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PSYCHOPHYSIOLOGICAL EFFECTS OF AGING - DEVELOPING A FUNCTIONAL AGE INDEX FOR PILOTS: II. TAXONOMY OF PSYCHOLOGICAL FACTORS

Siegfried J. Gerathewohl, Ph.D.
FAA Office of Aviation Medicine
800 Independence Avenue, S.W.
Washington, D.C. 20591

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16. Abstract

One of the major objectives of gerontological aviation psychology is to determine the psychological variables, functions, abilities, skills, and factors that underlie, consitutute or are associated with pilot performance and proficiency. They must be identified, analyzed, and measured if functional age is to be substituted for chronological age as a criterion for terminating an aviator's career.

The approaches use

~~Three methodological approaches are being used in this study to determine~~ the psycho~~logical and psychophysiological~~ factors, ~~which are thought to be~~ representative of ~~and essential to effective~~ pilot performance~~. They~~ consist of (a) the analysis of successful pilot behavior as displayed under simulated and operational conditions, (b) the analysis of unsuccessful pilot behavior (pilot error) as related to aircraft accidents, (c) the evaluation of pilot performance during the selection and training procedures as reported in the literature. By means of factor analyses, logical deductions, and clinical interpretations of the results obtained by various investigators, 14 factors are identified and described, namely (1) perception, (2) attention, (3) reaction, (4) orientation, (5) sensorimotor, (6) stamina, (7) cognition/mentation, (8) interpersonal relations, (9) decision making, (10) experience, (11) learning, (12) personality, (13) mechanical ability, and (14) motivation.

No attempt is made to assign weights to these factors or to rank them in accordance with their importance to flying proficiency. However, their relationship to age and the aging pilot is discussed.

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PSYCHOPHYSIOLOGICAL EFFECTS OF AGING - DEVELOPING A FUNCTIONAL AGE INDEX FOR PILOTS: II. TAXONOMY OF PSYCHOLOGICAL FACTORS

I. Introduction.

In an earlier report concerning age and the aviator, a survey was given about selected material on psychological variables and physiological functions pertinent to the development of a psychophysiological age index for pilots (40). Special emphasis was placed on studies concerning the effect of age on sensory, perceptual, mental, and neurophysiological functions and processes, and on certain personality traits and behavioral characteristics which seem to be related to the abilities and skills of operators of complex man-machine systems. It was concluded that although standardized tests and quantitative criterion measures are available for assessing such skills, they have not been used sufficiently or even considered as adequate or appropriate for substituting functional age for chronological age. In the area of behavioral sciences, investigations have shown that there is a definite correlation between test performance and chronological age, and that there are individuals who deviate from the established age-related performance curves. But no attempt has been made yet to determine the age-related performance decrement of the individual pilot, and to integrate the age-related deficit of the various functions into an index that could be used for terminating an aviator's career.

In the area of medical statistics, data are available which indicate loss of vital functions due to aging. A recent descriptive study of medical disqualifications and deaths in pilots of a major U.S. airline revealed that above the age of 45 years the rate of cardiovascular disqualifications increased from 5.2 cases per 1,000 man-years in the 45-49 year age group, to 12.7 in the 50-54 year group, and to 29.3 in the 55-59 year group (60). There was also an increasing death rate for the last two age groups. However, there are no scientific data available at this time which would show the rate of non-medical performance loss of aviators in the higher age brackets.

Thus, in the framework of this study project, we are now looking for information concerning the psychological and psychophysiological attributes, processes, and factors which (i) are associated with or constitute pilot performance, (ii) are age-related, and, (iii) in particular, may compromise proficiency of an aviator to the extent that he becomes subject to increased risk of an accident (50). It has been pointed out before that the process of aging is characterized by a progressive deterioration of psychological and physiological functions. Aging thus degrades performance and threatens proficiency. For the sake of clarity it must be mentioned that performance refers to the execution or action of a more or less specific function required of a pilot. Proficiency, however, relates to the integration of

a multitude of functions and is thought to be a desired, or even essential, quality of a safe pilot. The primary objective of the present report is to determine the psychological factors that underlie, constitute, and make up that complex phenomenon which is called pilot proficiency.

II. Regulatory Issues.

On December 1, 1959, the Federal Aviation Agency (FAA) issued Civil Air Regulations Amendments 40-22, 41-29, and 42-24 concerning maximum age limitations for pilots (88). It was pointed out in these documents that the number of active airline pilots age 60 and over had been increasing significantly during the past years and would continue to increase substantially during the years to come. In the absence of an age limit, this process would have led to a high percentage of older pilots; and these people would have been assigned to fly the newest, largest, fastest, and most sophisticated aircraft, carrying increasing numbers of passengers over the largest distances, operating out of and into the most congested airports near the largest cities and traveling in and through routes with the highest density of air traffic.

In exploring the ramifications of the medical problems involved, the nature of air carrier operations and of the air traffic of the future was considered. The indications were that the very large increments of older pilots that had already taken place were small in relation to the increases still to occur. Projection of the number of pilots who would have been in the 60-70 year age group, in an era of highly demanding air carrier operations involving the safety of many millions of passengers, indicated a relatively high probability of risk associated with the possibility of sudden incapacitation of some of the older pilots in the course of flight.

Such occurrences, due primarily to heart failures and strokes, could not be predicted reliably for any specific pilot on the basis of scientific tests and criteria available at that time. On the contrary, the evidences of the aging process are so varied in different individuals that it was thought impossible to determine accurately with respect to any individual whether the presence or absence of any specific defect in itself either would lead to or would preclude a sudden incapacitating attack. Any attempt to be selective in predicting which individuals were likely to suffer such an episode was considered futile under the prevailing circumstances and would not have been medically sound. Such a procedure, in light of the knowledge that a substantial percentage of any group of persons will suffer from incapacitation after reaching age 60, would therefore have been ineffective in eliminating the safety hazards involved.

In the context of the age 60 regulation, it was stated that the process of aging is associated with a decrease in the reactivity of the body system, leading to changes affecting performance; it is a process in which functional losses exceed gains. Many studies have since been made which demonstrate the

significance of these deteriorations in the performance of certain tasks. However, when knowledge developed by such studies is applied to a specific task, such as piloting an airplane, it frequently suffers from a lack of completeness and relevance; and this is often the case when dealing with the application of information about human capabilities. It was hoped then, as it is expected today, that scientific advances will help to solve the most pressing gerontological problems.

Some specific human capabilities depend on talent, reasoning, judgment, and experience which are retained for relatively long periods of time and may even improve with age (55). These underlying or constituent functions are operating from early maturity until some ill-defined maximum or state of decline is reached. In contrast, the ability to perform highly skilled tasks rapidly, to adapt swiftly to new and fast changing conditions, to process incoming information, to resist fatigue, to maintain physical stamina, and to perform efficiently in a complex and stressful environment, begins to decline, on the average, in early middle life and from thereon deteriorates in a more or less steady fashion. In addition, although experience, judgment and reasoning may be well preserved and compensate for some of the other functional losses, the ability to apply them, especially in non-routine or emergency situations, is progressively lost with age at a rate comparable to the loss of rapid performance of highly skilled tasks.

As mentioned before, the deterioration process selected to justify the proposed age limitation for pilots concerned foremost the body system and its related physical functions and their pathology. In the area of behavioral sciences, psychological tests indicate that there is a definite correlation between chronological age and performance, although there is no evidence of an identifiable disabling disease. Moreover, the aircraft accident rate increases with age and is highest for the years 60 or greater (46). The fact is, however, that the literature concerning age and flying or the aging pilot does not contain the type of information which permits a quantitative evaluation of pilot performance; in particular, it does not provide means, techniques, or a method which would indicate the cutoff point in the aviator's career due to aging. In order to arrive at a functional cutoff point, appropriate methods must be found and performance levels must be established. The large amount of information and human performance data accumulated during the past 20 years makes it now possible to review the present age limitations for air transport pilots and to propose practical solutions to the problem of identifying the functional endpoint of performance.

III. Methodological Considerations.

The primary objective in the attempt to develop a functional age index for pilots is to determine in what way an individual of a particular group differs in his behavior and performance at progressive points of time. Hence, we are trying, in a very general sense but under specific conditions, to describe the various relationships that determine the psychological and

physiological changes during the professional life span of an individual or of the total group composed of such individuals. The problems associated with such an effort are well known and have been discussed by many investigators (6,11,16,20,23,38,43,57,61,71) and cannot be repeated here. It must suffice to say that there are two major approaches, namely, cross-sectional and longitudinal studies, which are used to assess the effects of age and aging. A cross-sectional sample includes individuals of the same age group or cohort that is thought to be representative of either the entire or a specific population. In a longitudinal analysis, the stability or changes of behavior or characteristics of one (the same) individual or the same cohort across a certain period of time is assessed. It has been shown that both types of techniques are plagued by impurities, since there are inherent interactions among the age, developmental, generational, and environmental variables. It, therefore, has been recommended that mixed strategies be employed to disengage age from generational and environmental differences and thus decrease the variance of the results obtained from age studies.

Considering the assessment of age effects on the performance of aviators, the situation is just as complex. It must be recognized that the functional age concept requires a number of assumptions, such as the existence of essential factors which are associated with pilot performance, measurable psychological and physiological functions, and the interaction of age with generational as well as environmental variables. More specifically, this includes the different characteristics, background, training, and selection of pilots and aircrews, the different types of work and work environments, the different generational, social, and economic conditions, and the different requirements placed on the individual by the various types of work and work demands. The assessment of the age effects then requires various steps in the defining, ordering, or systematizing, analyzing, weighing, and correlating these items in regard to age and proficiency as an endpoint. We must be aware of the fact that this approach by necessity will be very complex and rather limited as to its accuracy and validity. However, a satisfactory solution of the problem can be envisioned by reducing the variables to a manageable number of critical factors, by distinguishing between the relationships between age dimensions and quantitative changes in performance levels, and by decreasing error variance to a statistically, or at least practically, acceptable amount.

One of the most important variables involved in determinable age changes concerns the ontogenetic or individual variance of the age-related functions that affect the validity of the functional age model and its application to the controversy about forced retirement. In an attempt to shed some light on this problem, Burney (22) compared persons who were found to be functionally older than attested by their chronological age and persons who were found to be functionally younger than their chronological age, with the majority of subjects who fell within ± 2 standard deviations (SD) of the mean of the group. Figure 1 shows a schematic representation of the trends found in three categories of the cohorts studied. Most subjects were found to be aging within the ± 2 SD of a progressive mean slope, some outliers were younger but

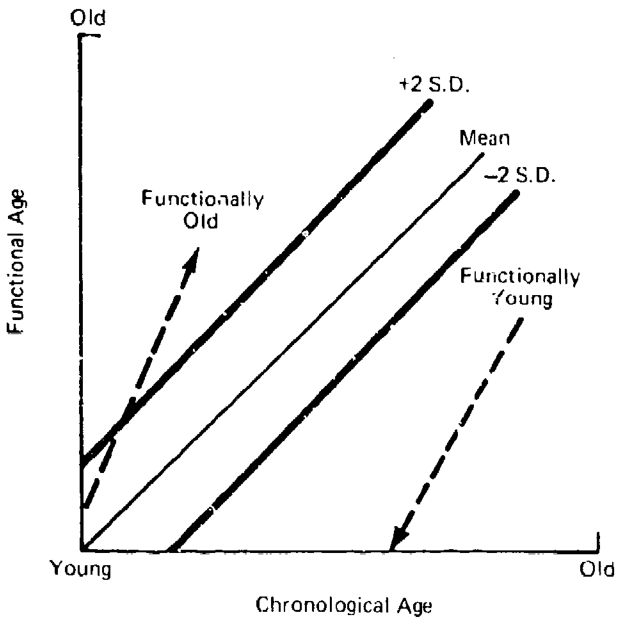

Figure 1. Chronological vs. functional aging in the 3 categories of the cohort studied by Burney (22). Most age within ±2 SD of a progressive mean slope. However, some who are younger age faster (upward arrow) and some who are elderly age slowly (downward arrow).

aging faster (upward arrow) and some were elderly but aging slower (downward arrow). Schonfield (72) has pointed out in a similar exercise that there are usually greater differences among a group of older people than there are among the young; i.e., the standard deviations of performance tend to increase considerably with age. This is illustrated in Figure 2. In this figure, each dot represents one score obtained from the Progressive Matrices Intelligence Test (72). It can be seen that some of the older subjects received higher scores than the majority of the younger ones, but that the means show an accelerated decline after the age 30 period.

There are two kinds of differences that must be considered when dealing with age-related factors: First, the aging process in man eventually affects all the physiological and psychological functions, but these functions deteriorate at different rates in a given individual. This means that an individual has many "ages", since the various biological systems and psychological functions age rather independently of one another over a good part of the adult life span. Secondly, there are differences in the rate of aging among individuals; i.e., some persons age fast, while others maintain their youth or vitality far beyond the usual onset of senescence. This phenomenon, as a matter of fact, is the main reason for the development of a functional

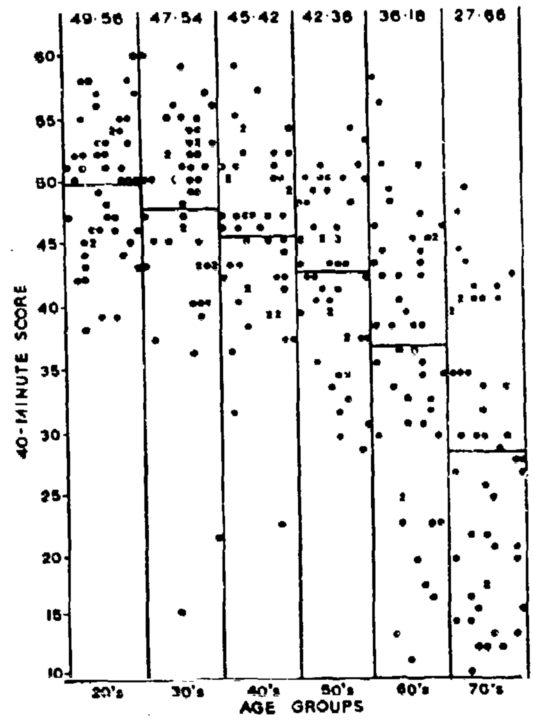

Figure 2. Distribution of 40-minute scores by men on progressive matrices. Means are indicated by horizontal lines. (Reproduced from Schonfield (72); original figure from A. Heron and S. Chown, Age and Function, London: J. & A. Churchill, 1967.)

age index: If all persons would age at the same rate, there would be no need for selective retirement. On the other hand, the rate of deterioration of certain functions, which seem to be characteristic of cohort behavior, appears to be relatively stable (31,71). This is one of the reasons for the conventional policy of collective or chronological retirement.

Regardless of the kind of model applied for the study of aging, it must be recognized that, in addition to the similarities and stability of trends, the differences among individuals will account for a great deal of the observed or calculated variance of measures. In particular, the psychological measurements show individual differences around the average age trend due to the various biases or forces to which the individual is exposed during its life. One outstanding example of the plasticity of certain psychologic or, more specifically, mental functioning is the human intelligence. In their controversy over the "myth of intellectual decline" during the later years of maturity, Baltes and Schaie (11) pointed out that research on intelligence in

adulthood and old age has revealed large interindividual differences, multidimensionality, multidirectionality, and the importance of generational differences. Accordingly, they conclude that the causes and patterns of individual changes are still not known and must be determined, if stable or invariant functions in aging persons are to be established.

Within the framework of their conceptual model these two authors (11) argue that a major share of the differences between younger and older persons and during adulthood and later age is due to ontogenetically invariant aging processes. In understanding aging, the problem has been to distinguish what is unique to the individual from what is a characteristic of the aging process. All the aforementioned factors, biological, psychological, social, economic, and historical or cultural, affect the aging of any given individual. The fact is that over the lifetime of any individual or cohort of individuals, both the behavior of the individual and the characteristics of his environment are changing (16). This is noteworthy in this context since we are dealing with highly specialized functions that are required for the successful control of an aircraft during periods of rapid technological changes and high personal demands. There is strong evidence available that much of the difference in mental and cognitive functioning between young and old is less due to a decline of intellectual capacity but more to the higher performance demands in successive generations (70). Some of the observed decrements, such as decreased performance on tasks involving speed of response, are undoubtedly age-related and show large individual differences (17). Recent experiments have shown that pilots' decision-making responses were highly individualistic and even independent of experience, training, and age. The responses which had to be made within a short-time interval were found to deteriorate with age (62).

With respect to aging studies of the type needed to determine the functional age of an individual or a group, there are various designs that aim at a sort of trend analysis of a particular variable or factor or in a multitude of variables or factors. The most promising approach to study such age trends still seems to be the longitudinal investigation, at least for our special objective. Some straightforward statistical procedures can be used to accomplish this task. They basically consist of the factoring or clustering of test results, observations, and other quantitative data. Examples of such efforts which lead to the various taxonomies will be given later in this report.

Nunnally (59) pointed out that precise conclusions about similarities of factors found in different analyses can hardly be drawn by just comparing the matrixes of factor loadings. However, factors established through different analyses can be compared or combined mathematically by correlation statistical procedures employing the scores or loadings which define the factors. In a later study, he attacked the problems associated with the individual differences by means of a "generalized component analysis" (59). This method is similar to that of any type of profile analysis performed on groups or cohorts in regard to differences in the results of a battery of psychological

tests or other measured variables. He stated that any factorial analysis can be used for this purpose, and that the factors obtained can be rotated or treated in such a way that optimizes the statistical solution. Such operations and comparisons are permissible if the same subjects are tested at various points in time. After such longitudinal data have been obtained by means of standardized test batteries, the similarities or differences of the factors or factor structures can be established at the desired age levels. In this way, comparative procedures can be useful for establishing a functional age index.

The details of a comparative factor analysis cannot be discussed here. Botwinick (20) reports Coan's attempt at a synopsis of factor change and ontogenetic considerations. Accordingly, the behavioral expression (e.g., the loading pattern) of a factor is necessarily different at various age levels although its "basic nature" remains the same. This implies a certain stability of the factor through or despite the aging process. In discussing some of the models available for distinguishing between relatively short-term intraindividual changes and stable factor structures, Baltes and Nesselroade (10) classified the factor relationships as follows:

Type A invariant loading patterns - stable factor scores

Type B invariant loading patterns - fluctuant factor scores

Type C noninvariant loading patterns - stable factor scores

Type D noninvariant loading patterns - fluctuant factor scores.

Briefly, Type A factors have the characteristics of ideal traits, i.e., high degree of stability and repeatability of the factor scores. Type B factors also show repeatable response patterns or state dimensions. For example, the variable cluster denoting the trait "dependency" may inhibit age-invariance, whereas age-specific situational variations result in a fair amount of intraindividual variations; i.e., low long-term stability. Type C factors are thought to have similar characteristics to those displayed during transition periods or critical life situations, where the loading patterns may show differences from one testing point to another while the basic nature of the factor remains unchanged. The Type D factor is not of interest in this context. Generally, the concept of stable factors (within certain limits) is not new, and it is a heuristic principle in the design of factor analytical strategies for aging studies.

A schematic system of the main topics involved in the study of individual differences which may also have a bearing on aging studies was designed by Wohlwill (96) and is shown in Table 1. It depicts the major problems and issues in a three-way classification in regard to the individual vs. dimension, univariate vs. multivariate design, and variance vs. stability. This latter concept is of great significance in the study of functional aging in

Table 1. Topics in the Developmental Study of Individual Differences As Outlined by Wohlwill (96)

A. Emphasis on change

Focus on	Single-variable case	Multivariate case
The individual	Individual patterns of change in z-scores and similar measures.	Changes in patterns of ipsative relationships among variables.
The dimension	Patterns of change in variability.	Changes in factorial structure; emergence of factors; developmental transformations.

B. Emphasis on stability

Focus on	Single-variable case	Multivariate case
The individual	Invariance of z-scores or other relativized measures at different ages.	Constancy of ipsative patterns; invariance of factor scores.
The dimension	Stability of individual differences for a variable across a time interval.	Invariance of factorial structure across age.

that it determines the amount of predictability of behavior patterns and performance. "Unstable" necessarily limits predictability. Predictability, on the other hand, can arise in several ways, and it can mean absolute invariance as well as regular or irregular changes in a more or less random fashion. The point here is that invariability of behavior can be measured mathematically and that the degree of continuity of performance can be predicted despite of the individual differences. Wohlwill (96) cites Kagan as having pointed out that continuity of behavior represents an assumption that would be difficult to eradicate from theoretical as well as from practical thinking; and there is convincing evidence (61) of the validity of this assumption.

In concluding the arguments concerning the role of individual and inter-individual differences in aging studies it appears that an acceptable solution may be found by the use of adequate psychological and functional tests. Such tests have been used more or less successfully to measure operator and pilot performance (among others, see 37,56,79,83,87,95). If valid correlations were established between the age-related variances, this would permit a more precise determination of the practical implications of the observed stability or changes in test scores. Then, a vigorous effort should be made to apply the test results for assessing age-related pilot performance and functional age indexing. It must be mentioned here that psychological tests have been administered in the past almost exclusively to predict success in flying training. Also, the measurement of pilot performance by means of such tests is mostly limited to military settings; air transport pilot performance is generally assessed, although periodically, by different means. A more general and systematic assessment of age-related performance seems to be possible, however, since there exists a variety of psychometric techniques, ranging from such simple tools as paper and pencil tests through the more complex psychomotor machines to the most sophisticated flight simulators and realistic check ride procedures. It thus appears that there is now enough

information available on age effects and age differences for various skills and their relation to occupational requirements to develop formal techniques and standards for appraising whether or not retirement of aviators is desirable or mandatory (70).

IV. Identification of Psychological Factors Related to Flight Safety.

A promising approach to the assessment of pilot proficiency is the identification of the skills underlying proficiency in pilot performance. This approach includes the taxonomic survey of the various parameters involved, the determination of the associated human factors, and the analysis of the psychological and physiological functions, performance variables and personality traits which are found in successful and non-successful pilots. We have, therefore, attempted to identify the psychological factors associated with (i) safe pilot behavior, and (ii) unsafe pilot behavior (or pilot error) as found in aircraft accidents.

A. Performance Criteria of Successful Pilots. We assume in this analysis that the human pilot is the operator of a complex man-machine system. According to Flexmann (36) pilot performance is based on the "ability to monitor many sources of information, maintain a high level of control over many variables, time-share a number of separate tasks, maintain a high density communication flow, and, at the same time, perform the leadership and crew coordination aspects of the job". By searching the pertinent literature on this type of behavior, which includes both operator and pilot performance, it appears that a great deal of information applicable to the identification and analysis of the pertinent factors is available. Examples of such taxonomies will be given in the following paragraphs, which list and describe operator tasks, activities, skills, and abilities, and the psychophysiological processes, functions, and behavioral characteristics involved in accomplishing these tasks.

In a study concerning the development of standardized procedures for defining the requirements of aircrew jobs in terms of testable traits, R. F. Wagner (92) of the American Institute for Research determined and tested psychological and psychophysiological factors which were thought to be needed for effective aircrew classification. It was proposed that the requirements of aircrew specialties could be represented by a practical number of job elements, which were common to all specialties but would vary in relative importance from one specialty to another. The pattern of requirements for a given job would be found by determining how often job performance of the kind defined by each element was a factor in deciding success or failure on the job. By weighting tests corresponding to each element in accordance with job-analysis findings, it would then be possible to make predictions of pilot success. Hence, the objectives of Wagner's (92) project were to (i) identify and define a representative group of job elements, (ii) develop a procedure which, by use of an appropriate technique, would permit persons with adequate training to perform job analyses, and (iii) test the validity of the job analysis procedure.

Identification and definition of the job elements were accomplished on the basis of information from all useful sources, such as job descriptions, test data, training results, and other personnel records. Moreover, approximately 2,000 critical incidents describing actual performance of aircrew members were obtained within the Training and Strategic Air Commands. An attempt was made to define a group of elements which was comprehensive, yet practical in number, and each of which was relatively independent, homogenous, and predictable by tests. The elements were reviewed and improved on the basis of several preliminary tryouts in the field.

TABLE 2. The Four Main Categories of Aircrew Behavior

Obtained From the Critical Incident Technique

As Reported by Wagner (92)

I. Learning and Thinking

This area concerns all mental processes dealing with abstract ideas. Included are such traits as memory, judgment, fluency, and foresight.

II. Observation and Visualization

This area concerns mental processes involving concrete things rather than ideas. Included are the abilities to locate points and objects with or without a reference system, to visualize objects in two- or three-dimensional space, and to identify and compare objects.

III. Sensorimotor Coordination

This area involves purposive movement of object. Included are finger dexterity, pressure control, speed of large muscle movement, and accuracy of large muscle movement.

IV. Motives, Temperament, and Leadership

This area is concerned with the basic reasons for doing things and the typical manner in which they are done. Included are character, values, fundamental interests, fixed habits, and characteristic modes of response.

During a 5-week program of interviews, ten Air Force bases were visited and 887 aircrew members were interviewed. Each interviewee was asked to describe critical incidents in which a pilot, flight engineer, or radar observer performed his job either in a particularly outstanding manner, or in a manner that might have seriously jeopardized the success of a mission (34). A total of 9,566 such incidents was reported, and for all but 198 the critical behavior in each was classified. The relative number of critical behaviors classified under each element produced a distinctive pattern of requirements for a given job. The general framework into which the tentative elements were grouped consists of the four main categories and is shown in Table 2. Two interviewing teams, operating independently, obtained results which were very similar. The distribution of incidents among job elements for each specialty is given in Table 3. The tryout elements most frequently mentioned by pilots are decision making, compliance with instructions and procedures, cooperation, accepting responsibility, and maintaining emotional stability. Table 4, finally, contains the refined job elements as related to pilot incidents and adjusted to suit available or possible psychological tests.

TABLE 3. The Distribution of Critical Incidents Among

24 Major Categories of Aircrew Requirements

Used by Wagner (92) for Defining Testable Traits

	Categories	Pilot (N=4004) %	Flight Engineer (N=2178) %
1.	Following Instructions, Procedures, Sequences	16.4	29.7
2.	Comprehending Written Material	0.0	0.1
3.	Making Computations	0.2	5.8
4.	Making Decisions	18.2	11.0
5.	Planning and Foreseeing	1.5	1.0
6.	Devising New Methods and Procedures	0.7	1.9
7.	Perceiving Stimuli	1.2	2.8
8.	Repairing Equipment	0.1	1.3
9.	Improvising Tools and Equipment	0.1	0.1
10.	Diagnosing Causes of Non-Typical Equipment Conditions	0.6	2.9
11.	Using Graphic Sources	0.1	0.3
12.	Interpreting Information From Instruments	1.0	4.4
13.	Maintaining Orientation By Visual Means	0.3	0.0
14.	Estimating Speed, Distance, Angles	1.4	0.1
15.	Discriminating Between Directions	0.2	0.2
16.	Visualizing	0.1	0.0
17.	Coordinating Overall Body Movement	0.1	0.1
18.	Actuating Fixed-Position Controls	1.4	2.7
19.	Moving Variable Controls	8.9	1.0
20.	Adapting to the Physical Demands of the Job	1.6	2.1
21.	Working With Others	14.6	6.2
22.	Accepting Personal Responsibility	13.9	15.4
23.	Subordinating Self	5.7	1.7
24.	Maintaining Emotional Stability	11.7	9.2

TABLE 4. Distribution of Pilot Critical Incidents Among Refined Job Elements Reported by Wagner (92)*

	Refined Job Elements	Incidents (%)
1.	Accepting Personal Responsibility	22.2
2.	Making Sound Decisions	15.5
3.	Working Effectively With Others	11.3
4.	Maintaining Proficiency Under Emotional Stress	11.2
5.	Accepting Organizational Responsibility	10.9
6.	Moving Variable Controls	9.5
7.	Learning and Remembering Verbal Materials	8.1
8.	Planning and Anticipating Problems	1.8
9.	Actuating Fixed-Position Controls	1.8
10.	Maintaining Proficiency Under Physical Stress	1.4
11.	Estimating and Identifying	1.3
12.	Recognizing and Defining Problems	1.0
13.	Noticing Changes	0.8
14.	Interpreting Data From Records and Instruments	0.8
15.	Showing Ingenuity	0.6
16.	Visualizing Mechanical Relations	0.6
17.	Interpreting Spatial Patterns	0.4
18.	Using Mathematical Reasoning	0.2
19.	Reading and Recording Data	0.2
20.	Making Numerical Computations	0.1
21.	Understanding Verbal Materials	0.0*
22.	Coordinating Overall Body Movements	0.0*
23.	Using Tools and Repairing Equipment	0.0*
24.	Fulfilling Size and Strength Requirements	0.0

* = less than 0.1%

In another study entitled "Age and Behavior", B. M. Shriver (76) also of the American Institute of Research used the critical incident technique to collect reports by airmen on the effects of aging in flying personnel. The group of persons interviewed consisted of active commissioned aircrew personnel, mainly pilots of jet aircraft. A background of reliable information was provided concerning physical, psychological and vocational indices for assessing individual competence, upon which Air Force policy concerning aging was supposed to be based. The results of this study led to the establishment of four major performance/behavior categories which are shown in Table 5. It was found that aircrew men, who reported adverse signs of age-related behavior, show symptoms of:

(i) physical and physiological deteriorations
(ii) loss of motivation and ability to acquire new skills
(iii) lowered levels of critical aspects of job proficiency
(iv) poorer relationships with coworkers
(v) lower morale and job satisfaction.

Five years later, the U.S. Air Force experimented with a battery of psychological tests for the study of age-related changes in aircrew performance (41). The job-element structure of this battery containing 16 items is shown in Table 6. From this and earlier studies, 14 tests were selected which were thought to measure the corresponding abilities. Of these 14 tests, the scores on the following eight indicated some decrease with age:

TABLE 5. Major Performance/Behavior Categories Based on Critical Incident Reports Analyzed by Shriver (76)

Categories	No. of Times Reported
I. Cognitive Processes	
A. Learning or acquiring new material or skills	9
B. Remembering	40
C. Problem-solving behavior	31
II. Sensorimotor Processes	
A. Meeting strength and endurance requirements for job	151
B. Meeting visual requirements for job	45
C. Meeting auditory requirements for job	21
D. Coordination and bodily flexibility and adaptability	31
III. Motivation and Temperament	
A. Accepting responsibility on the job	22
B. Retaining good attitude toward work and duties	34
C. Maintaining proficiency under physical stress	26
D. Maintaining proficiency under emotional stress	18
IV. Interpersonal Relations and Personal Adjustment	
A. Working and living compatibly with others	31
B. Adjustment to job	63

TABLE 6. Job-Element Structure Used by Glanzer, Glaser, and Richliss (41) for the Development of Age-Related Aircrew Performance Tests

1. Understanding verbal materials
2. Learning and remembering
3. Making numerical computations
4. Using mathematical reasoning
5. Recognizing and defining problems
6. Showing ingenuity
7. Planning and anticipating problems
8. Making sound decisions
9. Estimating and identifying: Reading data from records and instruments
10. Recording data from records and instruments
11. Interpreting data from records and instruments
12. Interpreting spatial patterns
13. Visualizing mechanical relations
14. Accepting personal responsibility
15. Accepting organizational responsibility
16. Maintaining proficiency under stress

TABLE 7. A Classification of Behavior Developed by Smode, Gruber, and Ely (78) for Assessing Aircrew and Spacecrew Proficiency

LEVEL I: ELEMENTAL TASKS

1. Follow routine preestablished checkout sequence
2. Position a set of discrete/serial controls
3. Obtain information from a dynamic display
4. Adjust instrument or other equipment items
5. Track
6. Communicate information
7. Utilize status or reference data
8. Directly observe external events
9. Compute
10. Select action from among alternate choices

LEVEL II: COMPLEX TASKS

1. Follow established procedures in inspection, calibration, and/or checkout
2. Acquire information from multiple sources
3. Make multiple control actions
4. Locate malfunctions in complex equipment
5. Remedy, repair, fabricate, and/or assemble complex equipment
6. Carry out computational/measurement sequences for determining status
7. Make command/control actions (Decisions) based upon processed multiple information

LEVEL III: MISSION SEGMENTS OF PHASES

1. Mission planning
2. Preflight (prelaunch) checkout
3. Departure (takeoff, Boost)
4. Navigation stages
5. Attitude control/power management
6. Subsystems managment
7. Life support/physical stress management
8. Rendezvous (intercept, rescue, refueling)
9. Weapon delivery
10. Defense (active, passive)
11. Data gathering (scientific/tactical)
12. Emergency procedures
13. Reentry/landing
14. Terminal mission operations

LEVEL IV: OVER-ALL MISSIONS (COMBINED MISSION SEGMENTS)

1. Extended terrestrial flight
2. Earth orbiting and return (scientific/experimental, reconnissance/intercept, weapon delivery)
3. Circumnavigation of planetary bodies
4. Rendezvous (inspection, repair, delivery, construction, and rescue in space)
5. Landing on a planetary body and return

Code Learning	Object Identification
Finding Relationships	Orientation to New Equipment
Instrument Comprehension	Reoriented Reading - Clocks
Mechanical Principles	Spatial Orientation

Smode, Gruber, and Ely (78) developed a task taxonomy that differentiated between levels as well as types of behavior. Various tasks predicted of crews were subsumed under the four levels or classes of tasks shown in Table 7. Their taxonomy was developed for measuring the proficiency of crews in advanced aircraft and space vehicles; and they adapted it for use in the design of weapon system training devices.

Armsby (5) proposed a method of task analysis in which tasks are defined in terms of the demand placed on the operator by the operational situation. In this approach, a demand is defined as a condition that limits, allows or prescribes certain activities of an operator. Initially, four composite measures were selected for the Task Demand Analysis (TDA), namely, difficulty (D), accuracy required (A), speed required (S), and a general factor called function complexity (C).

The composite measures were thought to be comprised of the demands which contribute to them. For example, 21 demands were selected for inclusion in the composite measure of difficulty. The demands were weighted on a scale from zero to seven and summed to obtain a composite score for the difficulty of a particular task in a given situation. Armsby (5) assumed that the four types of composite scores could be represented by vectors and combined into a single resultant or in some multidimensional figure such as a matrix. His tentative list of 32 task demands and three of their composite measures (D,A, and S) are shown in Table 8.

TABLE 8. List of Task Demands and Their Composite Measures as Developed by Armsby (5)

(A = accuracy required; D = difficulty; S = speed required)

Task Demands	Composite Measures
1. Input	
1. Signal type	A
2. Figure/ground ratio	D
3. Signal/noise ratio	D
2. Data Sensing	
1. Collateral information	A
2. Clarity	D, A, S
3. Similarity	D
4. Duration	D, S
5. Amount of change	D
6. Predictability	D, A, S
7. Simultaneous messages	D
8. Message interval	D
9. Percent action messages	D
10. Display-control location	D
3. Data Processing	
1. Type message used	A
2. Type data transformation	A
3. Degree of precision	A
4. Degree of urgency	S
5. Speed	
4. Data Generating	
1. Control of quality	D
2. Control of rate	D
3. Control of duration	D
4. Motor sensitivity	D, A, S
5. Type and degree coordination	D
6. Results available	D
7. Correction possible	D
8. Error seriousness	A
5. Output	
1. Message sent	D, S
2. Accuracy	D
3. Output repeatable	D
4. Results available	A
5. Correction possible	A
6. Error seriousness	A

TABLE 9. Classification of Behaviors by Berliner, Angell, and Schearer (15)

PROCESSES	ACTIVITIES	SPECIFIC BEHAVIORS
Perceptual	Searching for and Receiving Information	Detects Inspects Observes Reads Receives Scans Surveys
	Identifying Objects, Actions, Events	Discriminates Identifies Locates
Mediational	Information Processing	Categorizes Calculates Codes Computes Interpolates Itemizes Tabulates Translates
	Problem Solving and Decision Making	Analyzes Calculates Chooses Compares Computes Estimates Plans
Communication		Advises Answers Communicates Directs Indicates Informs Instructs Requests Transmits
Motor	Simple/Discrete	Activates Closes Connects Disconnects Joins Moves Presses Sets
	Complex/Continuous	Adjusts Aligns Regulates Synchronizes Tracks

In an attempt to find a task classification system suitable for the evaluation of military performance, Berliner, Angell, and Schearer (15) assessed several existing taxonomies. They arrived at their own classification system which is shown in Table 9. The more than 100 action verbs which indicated representative behavior were reduced to 50 specific mental and psychomotor activities which were subsumed under six broad types of activities and four major behavioral processes.

Another effort by Altman (1) was directed toward the improvement and refinement of the performance data which were already in the central store of descriptive human behavior. He suggested the following categories or types of psychological functions involved in operator and pilot performance:

Sensing - perceiving a difference in physical energies impinging on a single sense modality.

Detecting - perceiving the appearance of a target within a background field.

Discriminating or identifying - perceiving the appearance of a given target as distinct from other similar targets.

Coding - translating a perceived stimulus into another form, locus, or language, not necessarily involving the application of a sequence of logical rules.

Classifying - perceiving an object or target as representative of a particular class, where the objective characteristics of targets within the class may be widely dissimilar.

Estimating - perceiving distance, size, and/or rate without the application of measurement instruments.

Chaining or rote sequencing - following a pre-specified order in carrying out a procedure.

Logical manipulation - application of formal rules of logic and/or computation to an input as a basis for determining the appropriate output.

Rule using - executing a course of action by the application of a rule or principle.

Decision making - choosing one out of a field of alternative actions, including the following optimum strategy in non-rote behavioral sequencing.

Problem solving - resolving a course of action where routine application of rules for logical manipulation and decision making would be inadequate for an optimum choice. This would seem to imply the integration and adaptation of existing principles into novel, specialized, or higher-order rules.

One of the most extensive programs directed at the assessment of complex performance was reported by Chiles, Adams, and Alluisi (24) in 1968. Alluisi (2,3) had selected six synthetic tasks as having high face validity in representing the kinds of functions performed by operators of complex systems and had categorized these functions into seven areas as follows:

1. Watchkeeping, vigilance, and attentive functions, including the monitoring of both static (discrete) and dynamic (continuous) processes.

2. Sensory-perceptual functions, including the discrimination and identification of signals.

3. Memory functions, both short and long.

4. Communication functions, including the reception and transmission of information.

5. Higher-order functions, including information processing, decision making, problem solving, and nonverbal meditation.

6. Perceptual-motor functions.

7. Procedural functions, including such things as interpersonal coordination, cooperation, and organization.

This list has been criticized by Fleishman (35) as having too few categories to permit organization. He feels that task dimensions must be much more specific to be applicable to a large variety of tasks and situations. As an alternative to classifying tasks in terms of their characteristic, Theologus, Romashko, and Fleishman (85) developed a classification system based on basic human abilities. After extensive subjective scaling tests, they arrived at the list of 37 abilities shown in Table 10.

In 1971, R. T. White (94) of the Douglass Aircraft Company reviewed the literature in search of an adequate approach to the analysis of tasks performed by operators in complex man-machine systems. Representative task analysis models were surveyed, and a large number of task classification schemes or taxonomies were analyzed. Since his goal was to develop a technique for the experimental assessment of mental workload, his proposed matrix as shown in Table 11, differs from the usual task taxonomy in that it includes the primary task characteristics or demands, which determine the performance of a task, rather than simply listing the types of activities involved. The matrix provides a convenient format for depicting the relationships between these two kinds of variables that determine performance effectiveness. It also provides a meaningful basis for the quantification of workload.

TABLE 10. A Task Classification System Based on Abilities as Defined by Theologus, Romashko, and Fleishman (85)

1. Verbal Comprehension
2. Verbal Expression
3. Ideational Fluency
4. Originality
5. Memorization
6. Problem Sensitivity
7. Mathematical Reasoning
8. Number Facility
9. Deductive Reasoning
10. Inductive Reasoning
11. Information Ordering
12. Category Flexibility
13. Spatial Orientation
14. Visualization
15. Speed of Closure
16. Flexibility of Closure
17. Selective Attention
18. Time Sharing
19. Perceptual Speed
20. Static Strength
21. Explosive Strength
22. Dynamic Strength
23. Stamina
24. Extent Flexibility
25. Dynamic Flexibility
26. Gross Body Equilibrium
27. Choice Reaction Time
28. Reaction Time
29. Speed of Limb Movement
30. Wrist-Finger Speed
31. Gross Body Coordination
32. Multilimb Coordination
33. Finger Dexterity
34. Manual Dexterity
35. Arm-Hand Steadiness
36. Rate Control
37. Control Precision

TABLE 11. Task Taxonomy Matrix for Performance and Workload Analysis as Developed by White (94)

TASK TAXONOMY MATRIX			Demands: Procedural flexibility		Demands: Cognitive load		Demands: Sensory/motor load
Process	Activities	Duration (normal)	Start time	Duration	Complexity	Short-term Memory	Difficulty
Sensory	Discrete visual (e.g., read display)	NA		NA	NA		
	Continuous visual (e.g., search, scan)				NA		
	Auditory (e.g., receive voice message)			NA	NA		
Cognitive	Interpretation (e.g., decode, identify)		NA	NA			NA
	Decision-making						NA
	Self-scheduling	NA	NA	NA			NA
Motor	Simple/discrete action (e.g., activate)	NA		NA	NA		
	Complex/continuous action (e.g., alion, track)				NA		
	Verbal (output voice message)				NA		

NA = Not Applicable

TABLE 12. Functional Analysis of Behaviors Required in Civil Aircraft Operations

(Adapted from Barnhart et al. (12))

FUNCTION	SUBSYSTEM GOAL	CATEGORY OF BEHAVIORS
	INTELLECTUAL FUNCTIONS:	
COGNITION or COGNITIVE BEHAVIOR	Acquisition of information regarding the position or status of the aircraft, the system and the environment.	Attention to external objects, perception of information, awareness of that information, and appreciation of the implications of the information.
DECISIONS, DECISION-MAKING BEHAVIOR	Selection of rules and of actions with which to implement the assigned mission.	Decision-making, concept formation, problem-solving, management skills.
	IMPLEMENTATION FUNCTIONS:	
FLIGHT OR GROUND HANDLING	Control of the airplane's attitude and position in space and time.	Closed-loop manual tracking of airspeed, attitude, direction and altitude. Perceptual-motor skills.
SUBSYSTEM OPERATION	Operation of aircraft or ground-based subsystems in order to implement a decision.	Sequential discrete operation of switches and other controls; implementation of memorized or written procedures.
SUBSYSTEM MONITORING	Detection and identification of undesired subsystem states.	Monitoring behavior: scanning; vigilance.
COMMUNICATIONS BEHAVIOR	Transmission and reception of information.	Verbal and nonverbal communications skills.

Also in this context, the task analysis techniques proposed by Barnhart, Billings, Cooper, Gilstrup, Lauber, Orlady, Puskas, and Stephens (12) will be mentioned. In their attempt to discover the forms of human behavior associated with flight safety, the authors developed a sort of function analysis, whereby the term "function" is used to describe a "set of tasks which shares a common category of behavior". Table 12 shows the functions considered necessary to fulfill mission objectives in civil aircraft operations. The authors list cognitive behavior first in their table to indicate its priority among the various functions. It seems to be appropriate at this point to illustrate the importance of cognitive behavior for pilot performance by citing verbatim from Barnhart et al. (12):

> "Cognitive encompasses the behaviors by which a person becomes aware of, and obtains knowledge about, his relationship to his environment. In aviation, the flight crew and certain others (air traffic controllers, dispatchers) must all have knowledge of an airplane's location, status, and intentions. Cognition is the process whereby each person acquires and appreciates this information.
>
> "Having become cognizant of the required information, each of the persons in the aviation system is in a position to do something about it. The process involved is called decision making. A decision is the formulation of a course of action (from among a limited number of alternatives) with the intent of executing it. A decision may, of course, be to allow things to continue as they are: to do nothing.

"The execution or implementation of a decision involves one or more actions. The remaining functions (in Table 12) may be thought of as implementation functions: the actions one takes to implement a decision. In a sense, they all involve the same goal; they are separated, however, because they represent fundamentally different categories of behavior.

"A simple example may help to illustrate the functions as they apply to aircraft operations. Approaching an airport in a terminal area, a pilot may become cognizant that the visibility is excellent and that there are few aircraft operating in the area. Based on his appreciation of the implications of this information for his on-time arrival, the pilot may decide to "cancel IFR (Note: instrument flight rule) and to complete his flight by visual flight rules (Note: VFR), an alternative mode of operation open to him.

"Execution of this decision will require the use of some combination of the four implementation functions (see Table 12); it is important to note that the nature of the decision determines the appropriateness of the tasks which comprise the implementation functions. For example, certain subsystem operation tasks, which were appropriate when operating under IFR, are no longer appropriate when the decision to proceed under VFR has been made.

"In implementing this decision, the pilot must communicate his intentions to his crew and to the air traffic controller handling his flight. He must select and communicate on the radio frequencies appropriate to VFR operations (subsystem operation). He must continue to monitor the status of his aircraft and must also monitor the environment for conflicting traffic. He may elect to control the airplane manually (flight handling) or he may perform this function through the autopilot (subsystem operation)." (12)

In a more recent study concerning the psychological requirements for becoming a successful pilot, Steininger (81) identified the following relevant "basic abilities":

Conclusive and combinatory thinking in numerical, nonverbal terms
Short-term memory
Receptivity for acoustic or verbal information
Spatial orientation and understanding of directional relationships
Speed of perception and observation
Control of attention
Precision of sensori-motor coordination.

There are some studies available on the psychological requirements for glider pilots, which can be found in Neubert's (58) paper concerning the requirement analysis for training pilots for flights at high altitudes. Neubert analyzed the psychophysiological stresses encountered during soaring and the relationships between such stresses and the pilots' responses. Based on earlier investigations of the operational requirements of high-performance soaring and on functional analyses of the activities involved, the author (58) found the following behavior attributes and personality traits in a selected group of highly successful glider pilots:

Ability to follow established procedures (speed, flight course, and control of the aircraft).

Ability to quickly change from "feel-of-the-pants" (VFR) to instrument (IFR) conditions.

Psychophysiological stability (stamina).

Absence of feelings of anxiety or terror.

Balance between risk-taking and self-preservation and good judgment of the degree of risk involved in a certain action.

Ability to concentrate on short-term memory items.

Multiple-task performance capability.

Ability to change routine performance in accordance with special task demands.

Resistance against psychological fixations and mental or emotional blocks.

While the lack of a requirement for mechanical aptitude or skill in Steininger's (81) list is somewhat surprising, its omission from Neubert's (58) requirements of glider pilots is easily understandable. The risk-taking aspect in Neubert's ability list, on the other hand, seems to be typically associated with high-performance soaring.

The summary survey of the various taxonomies presented above is shown in Table 13. The six columns in Table 13 indicate the major tasks that military and civilian pilots are faced with; the task characteristics, job elements, and the required activities to accomplish these tasks; and the psychological functions, abilities, and factors involved in the performance of these tasks. Admittedly, this arrangement is arbitrary in that the different behavioral categories were defined conveniently to mitigate the intended compromise among the taxonomies. This, however, seems permissible to us since the principles of classifying task-related behavior were upheld.

TABLE 13. Major Categories of Tasks and Task-Related Behavior Applicable to Measuring Pilot Performance

Major Pilot Tasks (Military and Civilian)	Task Characteristics	Job Requirements or Job Elements	Specific Behavior or Activities	Psychophysiologic Functions & Abilities	Psychological Factors
1. **Mission & Flight Planning** a. Preflight orientation b. Preflight checkout	Task mode (discrete or continuous) Degree of complexity (extent & difficulty) Comprehension of information	Planning and foreseeing Comprehension of information Application of knowledge	Plans, requests Obtains information Follows instructions Observes & adjusts instruments Observes deviation from standards	Visualization Attention Distribution of attention Perceiving & interpreting stimuli Remembering	Perception (visual and auditory) Attention Cognition Learning
2. **Takeoff and Departure** a. Communication	Type of information (signal, message, etc.) Signal-to-noise ratio	Working with others	Asks for information Instructs others Answers questions	Signal detection Perceptual speed	Communication Perception Reaction time Alertness
b. Flight control (attitude, altitude, heading, speed)	Type of control (rate, quality & sensitivity)	Manual skill Understanding of mechanical principles Searching for information	Actuates controls Moves controls Adjusts controls Reads & adjusts instruments	Space perception Space orientation Gross body equilibrium Eye-hand coordination Response (reaction) time	Space perception and orientation Sensorimotor skill
3. **Cruise** a. Flight management (plant, power, subsystems, crew) b. Environmental control	Handling qualities Coordination Degree of automation Transfer function Man-machine interface Compensation of errors	Coordination of activities Closed-loop manual tracking Decision making Monitoring systems Making computations	Inspect systems Diagnoses systems errors & failures Finds relationships Analyzes status & reference data Reads & records data Makes decisions	Estimation of size Rate of change estimation Inductive reasoning Deductive reasoning Adjusting by experience Understanding of relations Forming of relations Decision making	Perception Cognition (mediational, mental, judgmental) Sensorimotor Personal relations Personal adjustment
c. Physical stress management		Stamina Meeting size & strength requirements	Working under stress Does physical work	Stress resistance Physical endurance	Stamina
4. **Flight & Mission Operations** (Rendezvous, attack, defense, weapon delivery, turnaround, etc.) a. Navigation b. Target identification c. Mission accomplishments	Degree of danger & risk Degree of effort required Results of effort observed	Intelligence Responsibility Ingenuity Improvisation Judgment Responsibility Data interpretation Adjustment to job demands	Plans operations Directs operations Identifies objects Observes external events Observes deviations from standards Locates failures Selects actions from alternate sources Cooperates with others	Watch keeping Static, dynamic & explosive strength Multi-limb coordination Manual dexterity Arm-hand steadiness	Vigilance Motivation Judgment Decision making Interpersonal relations Communication
5. **Emergency Procedures**	Speed, urgency Degree of danger or risk	Meeting emotional demands Recognition of problem Maintaining proficiency under stress	Detects failures Detects differences	Vigilance Emotional stability Judgment	Judgment Decision making Reaction
6. **Termination of Flight** a. Reentry or approach	Instructions	Following instructions	Follows instructions	Understanding of instructions	Judgment Self-discipline
b. Taxiing, parking, engine shutdown	Availability of information	Judgment	Uses judgment	Self-control	
c. Debriefing		Working with others			

An inspection of Table 13 shows that the multitude of pilot task-related behavior can be finally reduced to the following basic psychological factors:

1. Perception (visual, auditory, and tactual)
2. Reaction time and response behavior
3. Vigilance, attention
4. Sensorimotor abilities and skills
5. Motor activities
6. Learning
7. Cognition or mentation (including judgment and decision making)
8. Personality dependent behavior
9. Social behavior and organization.

It is obvious that the nine factors shown in the last column of Table 13 are very similar to the seven areas outlined by Alluisi (2,3) 10 years ago. This is not unexpected since his findings are used as part of our taxonomy. It thus appears that these factors must be considered in analyzing successful pilot behavior. Because of the nature of the different taxonomies used and the lack of quantitative information concerning these factors, it does not seem possible to assign weights or to rank them in regard to their importance to pilot performance. Also, they are not rated with respect to their age-dependency.

B. <u>Pilot Behavior Associated With Aircraft Accidents</u>. Another approach to the determination of pilot performance variables utilizes the analysis of pilot errors and human factors involved in aircraft accidents. For example, a detailed analysis of the causes of approach and landing accidents reported to the National Transportation Safety Board (NTSB) yielded five basic categories of human failure:

1. Visual perception
2. Operation of equipment
3. Inflight judgment or decisions
4. Professional attitudes or behavior
5. Pilot technique.

A comparison between the NTSB data and a study done by the International Civil Aviation Organization (ICAO) revealed the following causes:

	NTSB (1962-71)		ICAO (1961-70)	
1. Unprofessional attitude or behavior	47%	87%	43%	89%
2. Visual perception misjudgment	19%		29%	
3. Faulty pilot technique	21%		17%	
4. Inflight judgment or decision error	5%		5%	
5. Improper operation of equipment	6%		-	
6. Unknown	4%		7%	

Because of the high percentages, the first three categories deserve special attention. The seven probably major causative factors under the five NTSB categories are:

1. Visual illusions
2. Altitude awareness
3. Inflight judgment or decisions
4. Non-adherence to Standard Operating Procedures
5. Failure to make sure the aircraft is under control during routine irregularities
6. Failure to monitor critical flight instruments
7. Poor crew coordination.

There are many such lists available on the human error related accident causes, but only a few systematic analyses go beyond a mere description of the various types of causative factors. Several examples will be given to illustrate this point. Most of them are taken from the papers presented at the AGARD Aerospace Medical Panel Meeting held at Soesterberg, The Netherlands, September 7, 1973.

Based on findings by the Flying Safety Command of the German Federal Armed Forces, Falkenberg (33) analyzed the most frequent types of pilot error which contributed to 154 aircraft accidents of the German Armed Forces from 1967 to 1970. Only those accidents were considered in which the pilot was judged to be a primary or secondary cause of the mishap. The main objective of the study was to analyze the type of erroneous or otherwise inept pilot behavior which led to the accident. The author (33) obtained a total of 41 types of errors as shown in Table 14. The errors are related to the phases of flight such as ground preparations, taxiing, take-off, etc. It was found that certain types of errors occurred predominantly in certain phases; but no attempt was made by the author to rank them in a given set of conditions, nor were they related to the psychological factors that may have caused the erroneous behavior. Shannon and Waag (73) used the critical incident techniques to catalogue, describe and analyze operational flight crew errors involved in P-3 and F-4 Navy aircraft over periods of 7 and 5 years, respectively.

Human errors were categorized according to three types: (i) Vigilance errors, (ii) Procedural errors, and (iii) Perceptual-motor errors. Phases of flight operations were divided into four segments, namely, (i) Servicing/Pre-flight/Post-Flight; (ii) Start/Taxi/Shutdown; (iii) Takeoff/Landing, and (iv) Inflight. Table 15 lists the errors observed in both types of aircraft.

An incident, cost, and factor analysis of pilot-error accidents in U.S. Army aviation produced nine distinct, meaningful, and representative helicopter and airplane factors (64). A component score analysis yielded pilot and mishap background information used for the isolation of these factors. Ninety-one variables listed in Table 16 were obtained from accident reports submitted by the U.S. Army, Navy, and Air Force. As a multivariable tool for

Table 14. Error Categories Reported by Falkenberger (33) for Aircraft Accidents of the German Federal Armed Forces. Absolute (abs.) Frequencies Relate to the Number of Pilots.

	JET		HELICOPTER		PROP		TOTAL	
	abs.	%	abs.	%	abs.	%	abs.	%
1. Failure to secure preflight info	4	4.7	5	9.6	5	16.1	14	8.6
2. Non-perception of optical indications	13	15.1	5	9.6	2	6.7	20	12.3
3. Misreading of optical indications	1	1.2	-	-	-	-	1	0.6
4. Substitution errors	1	1.2	-	-	-	-	1	0.6
5. Non-perception of acoustical info	-	-	-	-	-	-	-	-
6. Non-perception of verbal info	-	-	2	3.8	-	-	2	1.2
7. Failure to secure verbal info	1	1.2	-	-	-	-	1	0.6
8. Non-perception of tactile info	1	1.2	-	-	-	-	1	0.6
9. Misinterpretation a/c attitude (vestibular)	6	7.0	-	-	-	-	6	3.7
10. Misinterpretation a/c attitude (optic ref)	-	-	-	-	-	-	-	-
11. Misinterpretation a/c attitude (others)	13	15.1	1	1.9	-	-	14	8.6
12. Misinterpretation geographical position	3	3.5	1	1.9	-	-	4	2.5
13. Misinterpretation posit w ref to rwy	6	7.0	-	-	-	-	6	3.7
14. Insufficient surveillance of airspace	5	5.8	4	7.7	2	6.7	11	6.8
15. Disregarding a/c pos in formation flight	4	4.7	-	-	2	6.7	6	3.7
16. Misinterpretation a/c pos in form flight	1	1.2	-	-	-	-	1	0.6
17. Non-perception of a/c, others	3	3.5	4	7.7	-	-	7	4.3
18. Non-perception of ground-obstacles	2	2.3	12	23.1	4	13.3	18	11.1
19. Misjudging flying altitude	17	19.8	10	19.2	2	6.7	29	17.9
20. Misjudging altitude and airspeed	3	3.5	1	1.9	2	6.7	6	3.7
21. Misjudging airspeed	6	7.0	2	3.8	1	3.3	9	5.6
22. Misinterpretation of technical emergency	4	4.7	2	3.8	-	-	6	3.7
23. Non-/too late recognition of emerg situation	16	18.6	-	-	2	6.7	18	11.1
24. Correct-uncoordinated/hurried reaction	13	15.1	2	3.8	1	3.3	16	9.9
25. Correct-delayed reaction	12	14.0	9	17.3	4	13.3	25	15.4
26. No reaction	3	3.5	3	5.0	2	6.7	8	4.9
27. False reaction	12	14.0	5	9.6	1	3.3	13	11.1
28. Confusion of controls	2	2.3	-	-	1	3.3	3	1.9
29. False verbal information	3	3.5	-	-	-	-	3	1.9
30. Failure to transmit necessary verbal info	5	5.8	2	3.8	1	3.3	8	4.9
31. Flying at too high a speed	-	-	3	5.8	-	-	3	1.9
32. False/incomplete normal procedure	14	16.3	13	25.0	9	30.0	36	22.2
33. False/incomplete emergency procedure	9	10.5	3	5.8	3	10.0	15	9.3
34. Non-performance of emergency procedure	-	-	-	-	2	6.7	2	1.2
35. Violation of minimum altitude	10	11.7	7	13.5	4	13.3	21	13.0
36. Performance of prohibited maneuvers	2	2.3	4	7.7	7	23.3	13	8.0
37. Failure to observe regulations	10	11.7	12	23.1	9	30.0	31	19.1
38. Deficient knowledge of regulations	-	-	1	1.9	1	3.3	2	1.2
39. Deficient knowledge of procedures	1	1.2	1	1.9	3	10.0	5	3.1
40. Non-abortion of mission	2	2.3	4	7.7	2	6.7	8	4.9
41. Poor flight planning	2	2.3	5	9.6	3	10.0	10	6.2

Note: The frequencies expressed in percent must not be added, since one and the same human factor might have been classified under more than one item. The frequencies relate to the number of pilots.

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Table 15. Analysis of Major Human Error Categories in P-3 and F-4 Aircraft As Reported by Shannon and Waag (73)

	P-3 Aircraft			F-4 Aircraft		
	% P-3 Error	Major Accidents	Fatalities	% F-4 Error	Major Accidents	Fatalities
AIRCREW HUMAN ERROR IN THE P-3 AND F-4 AIRCRAFT BY MAJOR ERROR CATEGORIES.						
A. Vigilance Errors						
1. Poor instrument scan.	.9	1	8	8.5	16	18
2. Inadvertent/incorrect actuation of cockpit controls.	4.1	--	--	5.9	3	--
3. Poor monitoring, poor supervision.	2.0	--	--	3.4	--	--
4. Poor preflight inspection-discrepancies not noted.	4.1	--	--	2.7	1	--
5. Poor external visual lookout.	--	--	--	1.8	7	6
6. Misinterpretation of hand signals.	--	--	--	.5	--	--
7. Inadvertent engine ingestion.	--	--	--	.7	--	--
Vigilance Error Totals:	11.0	1	8	23.6	27	24
B. Procedural Errors						
1. Improper servicing/refueling/fuel transfer procedures.	21.7	--	--	.9	1	--
2. Improper ordnance handling/release procedures.	2.6	1	13	2.5	1	1
3. Improper maintenance/troubleshooting procedures.	3.3	--	--	1.1	1	1
4. Poor engine operating/restarting procedures.	2.6	--	--	.7	1	--
5. Checklists not complete.	1.2	1	--	3.9	5	3
6. Improper procedures used in a takeoff or a landing.	3.5	--	--	4.1	7	1
7. Poor communication procedures, pertinent information not communicated.	.6	--	--	3.2	1	1
8. Improper instrument/navigation procedures.	1.2	1	12	4.1	4	0
9. Improper emergency procedures.	1.2	--	--	4.2	1	--
10. Improper procedures within a thunderstorm area.	.9	--	--	--	--	--
11. Poor judgment, flight should not have been flown.	--	--	--	1.1	1	2
12. Performance of unauthorized actions.	--	--	--	1.8	5	8
13. Parts not properly secured by aircrewman, not checked for security.	23.3	--	--	1.8	--	--
14. ~~Improper survival/ejection procedures.~~	--	--	--	13.4	--	13
Procedural Error Totals:	61.2	3	25	42.6	38	30
C. Perceptual-Motor Errors.						
1. Misjudged safe distance or speed.	3.8	--	--	7.6	15	5
2. Poor control of brakes.	16.8	--	--	4.6	5	--
3. Poor rudder control.	1.7	1	1	2.3	3	--
4. Poor aileron control.	.6	--	--	.2	--	--
5. Poor power/nose control-coordination of both controls.	.3	1	6	3.0	3	--
6. Poor throttle control.	4.3	2	--	4.3	11	2
7. Poor elevator control.	.3	--	--	11.9	22	17
Perceptual-Motor Error Totals:	27.8	4	7	33.9	59	24

Table 16. Variables and Occurrences for 1520 FY 71-72 Helicopter and 452 FY 69-71 Airplane Pilot-Error Accidents as Reported by Ricketson, Johnson, Branham, and Dean (64)

Category	Variable	Helicopter	Airplane
Supervisory	1 Inadequate briefing	102*	16*
	2 Ordered flight beyond capability	21	2
	3 Poor crew coordination	244*	35*
	4 Other	59	7
Preflight	5 Faulty flight plan	39*	15*
	6 Faulty preflight of aircraft	187*	48*
	7 Faulty preparation of personal equipment	13	3
	8 Hurried departure	42*	14*
	9 Delayed departure	12	1
	10 Inadequate weather analysis	74*	12*
	11 Other	20	1
Experience/Training	12 Inadequate transition	36*	10*
	13 Limited total experience	262*	64*
	14 Limited recent experience	150*	34*
	15 Failure to use accepted procedures	781*	236*
	16 Other	22	4
Design	17 Design of instruments, controls	9	6
	18 Location of instruments, controls	8	5
	19 Failure of instruments, controls	18	1
	20 Cockpit lighting	6	1
	21 Runway lighting	1	2
	22 Lighting of other aircraft	1	0
	23 Personal equipment interference	7	1
	24 Workspace incompatible with man	8	2
	25 Other	27	1
Communication	26 Misinterpreted communication	22	7
	27 Disrupted communication	25	3
	28 Language barrier	15	1
	29 Noise interference	10	2
	30 Other	7	0
Psychophysiological	31 Food poisoning	0	0
	32 Motion sickness	4	0
	33 Other acute illness	1	0
	34 Other pre-existing disease/defect	6	0
	35 Get-homeitis	27	13*
	36 Hangover	2	0
	37 Sleep deprivation	28	2
	38 Fatigue, other	79*	12*
	39 Missed meals	32	3
	40 Drugs, medical officer prescribed	2	1
	41 Drugs, other	1	1
	42 Alcohol	6	4
	43 Visual illusions	10	2
	44 Unconsciousness	2	0
	45 Disorientation/vertigo	75*	11*
	46 Hypoxia	1	3
	47 Hyperventilation	1	0
	48 Dysbarism	0	0
	49 Carbon monoxide poisoning	0	0
Psychophysiological	50 Boredom	13	5
	51 Inattention	278*	88*
	52 Channelized attention	163*	32*
	53 Distraction	84*	32*
	54 Preoccupation with personal problems	17	3
	55 Excessive motivation to succeed	83*	15*
	56 Overconfidence	145*	60*
	57 Lack of self-confidence	19	8
	58 Lack of confidence in equipment	12	8
	59 Apprehension	98*	21*
	60 Panic	26	6
	61 Other	25	5
Environmental	62 Acceleration forces, inflight	0	1
	63 Acceleration forces, impact	9	2
	64 Decompression	0	0
	65 Vibration	7	0
	66 Glare	31	5
	67 Smoke, fumes	6	2
	68 Heat	11	1
	69 Cold	1	1
	70 Wind blast	20	9*
	71 Visual restriction—haze, darkness	104*	25*
	72 Visual restriction—icing, window fog	5	3
	73 Visual restriction—dust, smoke in aircraft	6	1
	74 Weather, other than visual restriction	45*	17*
	75 Other	57	8
Other	76 Habit interference, used wrong control	9	8
	77 Confusion of controls, other	31*	23*
	78 Misread instrument(s)	15	6
	79 Misinterpreted instrument readings	27	5
	80 Misled by faulty instrument	24	8
	81 Visual restriction by equipment structure	17	7
	82 Task oversaturation	41*	12*
	83 Inadequate coordination or timing	377*	102*
	84 Misjudged speed or distance	588*	139*
	85 Selected wrong course of action	531*	215*
	86 Delay in taking necessary action	509*	201*
	87 Violation of flight discipline	193*	45*
	88 Navigational error	20	7
	89 Inadvertent operation self-induced	194*	95*
	90 Inadvertent operation mech. induced	24	3
	91 Other	56	8

*Selected for analysis

this investigation, factor analysis was chosen in order to extract representative clusters of factors from the large number of variables. Only 29 of the 91 accident report variables were selected for analysis since they accounted for a large proportion of the helicopter aircraft cases. The final factors identified for both fixed and rotary wing aircraft pilot error were:

1. Disorientation
2. Over-confidence
3. Procedural decisions
4. Crew coordination
5. Precise multiple control
6. Limited experience
7. Task oversaturation
8. Attention
9. Other weather (helicopter)/ Inadequate briefing (aircraft).

The identification of the nine error groups led Sanders and Hoffman (66) to correlate them with specific personality traits. Cattell's Sixteen Personality Factors Questionnaire (16 PF), the Mehrabian Achievement Scale, and a dynamic Decision Making Task (under risk conditions) were administered to 51 Army aviators, and the scores from these tests were correlated with pilot-error accident involvement. While three of the 16 personality factors in this sample were found to discriminate between accident related and accident unrelated behavior (the accident-free aviators were generally more "self-sufficient", "imaginative", and "forthright"), this was not confirmed by the results obtained from a second sample (67). Instead, the findings indicated that individual differences in personality characteristics of the aviators prevented consistent identification of traits associated with pilot error groups. However, the "Adventure Scale" developed recently by Levine et al. (47) in a study of attitudes and accidents aboard an aircraft carrier correlated significantly with accidents in two samples of enlisted men and aviators.

Human factors in Air Force aircraft accidents were classified by Lewis (48) in eight major groups:

1. Supervisory factors
2. Preflight factors
3. Experience/training factors
4. Design factors
5. Communication problems
6. Psychophysiological factors
7. Environmental factors
8. Other factors.

Of these, the psychophysiological factors shown in Table 17 and Table 18 are of special interest. Based on the frequency of occurrence, such behavior as "selected wrong course of action", "delay in taking necessary action", "violation of flight discipline", "misjudged speed or distance", and "channelized attention" contributed significantly to the accidents analyzed by Lewis (48). Other highly involved factors were supervision ("poor crew coordination") and limited experience or training ("failed to use accepted procedure").

TABLE 17. Psychophysiological Factors in 1971-1973 Air Force Aircraft Accidents as Reported by Lewis (48)

Factor	Occurrence by Year 1971	1972	1973
Food Poisoning	0	0	0
Other Preexisting Disease/ Defect	0	0	0
Get-Homeitis	0	0	0
Hangover	0	1	0
Sleep Deprivation, Fatigue	0	0	0
Fatigue, Other	0	1	0
Missed Meals	0	0	0
Drugs Prescribed (Medical Officer)	0	0	0
Drugs, Other	0	0	0
Alcohol	0	1	0
Visual Illusions	0	2	3
Unconsciousness	0	1	0
Disorientation/Vertigo	6	8	4
Hypoxia	0	1	0
Hyperventilation	0	1	0
Boredom	0	0	0
Inattention	5	5	5
Channelized Attention	7	10	6
Distraction	3	9	9
Preoccupation with Personal Problems	0	0	0
Excess Motivation to Succeed	1	2	2
Overconfidence	6	1	2
Lack of Self-Confidence	0	0	0
Lack of Confidence in Equipment	2	2	0
Apprehension	1	5	0
Panic	2	1	0
Other Psychophysiological Factors	1	5	3
TOTAL	34 (9%)	56 (10%)	34 (10%)

TABLE 18. Non-Psychophysiological Factors in 1971-1973 Air Force Aircraft Accidents and Reported by Lewis (48)

Factor	Occurrence by Year 1971	1972	1973
Habit Interference, Used Wrong Control	2	2	1
Confusion of Controls, Other	2	1	0
Misread Instrument(s)	1	0	0
Misinterpreted Instrument Reading	0	1	0
Misled by Faulty Instrument	2	3	1
Visual Restriction by Equipment Structure	1	2	8
Task Oversaturating	2	2	4
Inadequate Coordination or Timing	2	5	5
Misjudged Speed or Distance	10	25	9
Selected Wrong Course of Action	25	43	16
Delay in Taking Necessary Action	28	40	14
Violation of Flight Discipline	16	24	21
Navigational Error	5	4	1
Inadvertent Operation, Self-Induced	9	7	6
Inadvertent Operation, Mechanically Induced	5	7	2
Other Factors to be Considered	3	13	2
TOTAL	113 (30%)	179 (31%)	90 (28%)

Six factors were identified by Dean and Thatcher (30) which elucidate the dilemma of the pilots. They are:

1. Rapidity of events
2. Departures from preplanned parameters
3. Target acquisition
4. Time sharing
5. Concentration of attention
6. Late realization or delayed reaction.

TABLE 19. Fatal Accidents to Public Transport Aircraft

Over 5,700 kg (1962-1971 Inclusive) and reported by Shuckburg (77)

Distribution of predominant flight crew causal groups

CAUSAL GROUP	PERCENTAGE
Incorrect operation in instrument weather conditions	30%
Inadequate pre- and in-flight planning	20%
Poor judgment	17%
Lack of supervision	8%
Misuse of aircraft controls	7%
Errors by flight crew other than pilot	5%
Miscellaneous and undetermined	13%

A breakdown of flight crew causal factors derived from over 400 fatal accidents to public transportation aircraft that occurred worldwide during the period 1962-1971 yielded the results (77) presented in Table 19. The table shows that the major cause of fatal accidents was the incorrect operation of the aircraft in instrument weather conditions. This group included such variables as the use of incorrect instrument procedures, operations in weather conditions unsuitable for flight, and operation below authorized minima.

Recently, investigators from the Aviation Research Laboratory of the University of Illinois analyzed general aviation accidents in which pilots were thought to be a contributing cause or factor (44). Statistics from the NTSB Automated Aircraft Accident and Incident Information System from 1970 (DSN-A9000X70) through 1974 (DSN-A9000X74) were used in this analysis. Pilot cause/factors from the NTSB data were classified into three behavioral categories, namely procedural, perceptual-motor, and decisional activities. Then the numbers of both fatal and nonfatal accidents which occurred during the 5-year period were determined for each of these categories. The results of the analyses are shown in Table 20.

A classification such as that may provide somewhat arbitrary results because, in many cases, cause/factors have been listed under more than one behavioral category while others do not fit very well under any of the three categories. The classification was therefore considered as preliminary by the authors (44).

TABLE 20. Number of Fatal and Nonfatal General Aviation Accidents in Which the Pilot in Command Was Listed as the Cause or a Factor for all Data Between 1970 and 1974.

(Data for the three behavioral categories are from Jensen et al. (44).)

	Procedural Activities	Five-Year Totals Fatal	Five-Year Totals Nonfatal
1.	Failed to extend landing gear	1	255
2.	Failed to retract landing gear	4	14
3.	Failed to use or incorrectly used miscellaneous equipment	14	62
4.	Improper IFR operation	110	66
5.	Improper fuel management	105	1231
6.	Improper starting procedure	1	30
7.	Failed to assure gear down and locked	1	207
8.	Misused or failed to use flaps	27	235
9.	Inadvertently retracted landing gear	0	104
10.	Retracted gear prematurely	1	26
	Total for Procedural Activities	264	2230
	Percent of total pilot-caused accidents	4.6	8.6

	Perceptual Motor Activities	Five-Year Totals Fatal	Five-Year Totals Nonfatal
1.	Became lost/disoriented	68	248
2.	Delayed action in aborting takeoff	5	236
3.	Delayed in initiating go-around	32	380
4.	Failed to see and avoid other aircraft	128	196
5.	Failed to see and avoid object	165	757
6.	Failed to maintain flying speed	846	1825
7.	Misjudged distance, speed, altitude, clearance	351	2864
8.	Failed to maintain adequate rotor RPM	16	153
9.	Improper operation of powerplant controls	53	685
10.	Improper operation of brakes/flight controls	1	688
11.	Improper operation of flight controls	154	569
12.	Improper level off	10	1596
13.	Improper compensation for wind	12	550
14.	Control interference	0	1
15.	Improper recovery from bounced landing	5	811
16.	Spatial disorientation	528	60
17.	Failure to maintain directional control	13	1978
18.	Premature liftoff	11	302
19.	Failed to abort takeoff	26	257
20.	Failed to initiate go-around	8	637
21.	Exceeded design stress limits of aircraft	121	16
	Total for Perceptual-Motor Activities	2564	14809
	Percent of total pilot-caused accidents	45.0	57.2

	Decisional Activities	Five-Year Totals Fatal	Five-Year Totals Nonfatal
1.	Operation of aircraft with known deficiencies	84	201
2.	Operation beyond experience/ability	170	368
3.	Continued VFR into known adverse weather	717	343
4.	Continued flight into known severe turbulence	18	7
5.	Improper inflight decisions/planning	236	597
6.	Exercised poor judgment	235	767
7.	Operated carelessly	7	38
8.	Selected unsuitable terrain	22	1230
9.	Initiated flight into adverse weather	124	61
10.	Psychological condition	11	4
11.	Selected wrong runway	11	341
12.	Failed to follow approved procedures	145	425
13.	Inadequate preflight planning or preparation	511	2341
14.	Lack of familiarity with aircraft	121	611
15.	Started without proper assistance	6	89
16.	Taxied, parked without proper assistance	0	67
17.	Left aircraft unattended	1	8
18.	Diverted attention from operation of aircraft	111	501
19.	Inadequate supervision of flight	62	610
20.	Spontaneous improper action	15	119
21.	Misunderstood orders/instructions	3	20
22.	Incapacitation	50	7
23.	Physical impairment	203	65
24.	Inadequate training	0	5
25.	Direct entry	9	14
	Total for Decisional Activities	2872	8839
	Percent of total pilot-caused accidents	50.4	36.1

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Nevertheless, some useful information can be gained from an examination of the statistics presented in Table 20. For instance, a majority of the nonfatal pilot-caused accidents (57.2 percent) was the result of faulty perceptual-motor behavior. The most significant factors were failure to maintain flying speed, misjudgment of distance, speed, altitude, or clearance, all of which are included in the aspect of pilot judgment. On the other hand, a majority of the fatal pilot-caused accidents (50.4 percent) were the result of faulty decisional behavior. The most significant factors in this case were the familiar "continued VFR into known adverse weather" and "inadequate preflight planning or preparation" items. It is apparent from these figures that deficiencies in "perceptual motor" and "decisional activities" resulted in 95.4 percent of the accidents analyzed by the University of Illinois.

In evaluating the effect of faulty pilot judgment on general aviation accident statistics, two aspects of the deciding function must be considered. The first is the general judgment process which requires the pilot to make a thorough evaluation of the available information based on his recollection of previous experiences or pertinent knowledge. Included in this aspect of the decisional functions are all items listed as "Decisional Activities". The willingness of pilots to never exceed regulatory limitations, their ability to properly evaluate all conditions affecting the safety of a given flight, and their acceptance of safety margins accordingly are criteria of pilot judgment which deserve high consideration and ranking within the hierarchy of pilot judgment and decision capabilities.

The second aspect concerns actions in the perceptual-motor area. Here, information is sensed, recognized, and transformed into actions. Under certain conditions, particularly under time constraints, a thorough evaluation of the information may be bypassed by the pilot, and a hasty decision to manipulate the controls is made. Included in this category are distance, speed, altitude, and clearance judgments. It appears from the accident statistics that both aspects of the deciding function are important to safe flight.

The authors of this study (44) concluded that every pilot has a flexible decision or judgment tendency, which is based or brought about by attitudes, phobias, priorities, motives, self-esteem, and other personality-related factors. They contribute to the decision process in the flight situation. The inflight decision process is further complicated by the fact that flying can be a very personal experience to certain people. High levels of emotional involvement, whether in ordinary or emergency flight situation, can affect decision making adversely. In contrast, the pilot who always maintains the ability to rank flight alternatives in their order of merit and acts accordingly in all situations is thought to possess good judgment and thus avoids accidents.

TABLE 21. Major Categories of Error Conditions, Pilot Error, and Psychological Factors Involved in Aircraft Accidents

(The column on results of factor analysis is based on the factor analysis of 91 variables selected by Ricketson et al. (64).)

Sequence or Incidence of Occurrence	Implementation Functions	Pilot Error Conditions	Observed Erroneous Behavior	Results of Factor Analysis	Psychological Factors
Preflight Planning Mission briefing Servicing Inspection Weather briefing Geography Taxiing Communication	Acquisition of information Selection of rules VFR/IFR operations Air Traffic Control Instructions & orders Flight schedule Cockpit procedures Clearance procedures	Inadequate preflight information/briefing Inadequate weather analysis Nonperception of visual signals Faulty communication Poor preflight inspection Improper servicing, refueling, fuel transfer Improper start procedure	Started without proper assistance Selected wrong course of action Taxied without proper assistance	Inadequate Briefing and Other Weather (Identified by inadequate briefing, weather, other visual restriction, faulty flight plan, and inadequate weather analysis)	Foresight (ability to plan)
Flight Phase Takeoff Rotation Climb Departure Communication Flight control Environmental control Orientation Navigation Solo flying Formation flying Cruise Combat Acrobatics Hovering Rendezvous Holding Inflight refueling	Course selection Systems operation Transmission & reception of information Control of aircraft Instrument control Control of airspace Detection & correction of unwanted states Personal equipment Technical procedures Toxic gases & fumes Acceleration forces Noise & vibration Heat, cold & windblast Hypoxia & dysbarism Speed (rapidity of events) Visual restrictions Lighting (including glare and darkness) Quantity, quality & flow of communication Workload Cockpit design Crew coordination Sleep deprivation Stress, hunger & fatigue Target acquisition Attack, defense & retreat Alcohol, medication, drugs Habit formation Desynchronization Sickness & injuries Turbulence & windshear	Improper transition Flight beyond capacity Hurried/delayed departure Failure to follow procedure (violation of rules & discipline) Misjudgment of altitude Nonperception of ground obstacles Geographic dislocation (disorientation) Insufficient surveillance of airspace Disregard of position during formation flight Misjudgment of speed and distance Improper instrument or navigation procedure Uncoordinated actions Poor instrument scan Faulty instruments Misinterpretation of instruments Improper fuel management Inadvertent or incorrect operation or actuation of controls Failure to transmit needed information Inadequate coordination or timing of action Delayed actions No or false reaction False or incomplete procedure Misinterpretation of emergency condition False or incomplete emergency procedure Failure to abort mission Unfamiliar with aircraft systems Improper ordnance or weapon handling	Rotated prematurely Failed to retract landing gear Delayed or failed to abort takeoff Misused or failed to use flaps Inadvertently or prematurely retracted landing gear Failed to use or incorrectly used equipment Became confused, disoriented & lost Failed to see and avoid obstacles and aircraft Failed to maintain speed Failed to maintain altitude Misjudged distance, speed, altitude or clearance Failed to maintain proper rotor RPM Continued VFR into adverse weather Continued flight into severe turbulence Exceeded design limits Misunderstood orders or instructions Exercised poor judgment, operated carelessly Failed to follow approved procedures Diverted attention from operation of aircraft Was preoccupied with personal problems Showed excessive motivation to succeed Was overconfident Lacked self-confidence Did not trust equipment Became apprehensive and panicked Hyperventilated	Attention (Identified by inattention, distraction, confusion of controls & channeled attention) Disorientation (Identified by disorientation, vertigo, visual restriction, haze/darkness, inadequate weather analysis, faulty flight plan, other weather) Overconfidence (Identified by overconfidence, violation of flight discipline, excessive motivation, to succeed, get-home-itis) Procedural Decisions (Identified by failure to use accepted procedures, selected wrong course of action, inadverted operation, violation of flight discipline) Crew Coordination (Identified by inadequate briefing, poor crew coordination, inattention) Precise Multiple Control (Identified by inadequate coordination or timing, misjudgment of speed or distance, delay in taking necessary action, limited recent or total flight experience) Limited Experience (Identified by limited total experience, limited recent experience, excessive motivation to succeed, inadequate transition, confusion of controls, other, and apprehension)	Perception (visual, auditory & tactual) Attention Orientation (spatial and geographic) Self-discipline Self-confidence Motivation Decision making Judgment Self-discipline Attention Interpersonnel relations Motor control Sensorimotor skill Multiple reactions Response time Flight experience Spatial relations Flight experience Motivation Calmness/composure Stamina
Landing Phase Letdown Approach Go-around/Wave-off Flare Touchdown	Airport and runway conditions	Wrong radio channels Poor monitoring or supervision Inattention, distraction and channeled (narrow) attention Incomplete checklist Wrong approach plate Misinterpretation of position to runway	Selected wrong runway Selected unsuitable terrain for landing Delayed initial go-around Failed to inform air traffic control of actions Failed to extend landing gear Failed to assure landing gear down and locked	Task Oversaturation (Identified by distraction, channelized attention, task oversaturation, apprehension, fatigue, other)	Channel capacity Stamina
Postflight Phase Shutdown Taxiing Parking Mission briefing		Taxiing & parking without assistance Poor brake and throttle control	Parked without proper instruction or assistance Left aircraft unattended		

C. Essential Psychological Factors. The data in Tables 14 through 20 were systematically grouped and listed in Table 21. The left column in this survey table shows the phases of operations or flight during which the incidents and accidents occurred. It is also an arrangement of the pilot errors in the sequence of operation. The concept of "implementation functions" listed in the second column was adopted from Barnhart, et al. (12). They indicate the major items, actions, and procedures necessary for or involved in the execution of the phases shown in column one. The pilot error conditions given in the third column are also arranged in a sequential or time-line fashion and depict potential failure causes or faulty procedures. They are expanded in the fourth column to describe in more detail the erroneous pilot behavior. The fifth column contains the results of the factor analysis of the accident report variables extracted by Ricketson et al. (64) and listed in Table 16. They produced the nine distinct, meaningful, and representative aircraft and helicopter factors listed in the fifth column. The psychological factors shown in the last column on Table 21 were deduced primarily from these factors, but also from other major factors contained in Tables 14 through 20.

Since we are dealing again with input obtained from various sources, weights or rank orders were not established for the final 17 factors in column six of Table 21.

By comparing the results of the two survey tables (columns six in Tables 13 and 21), the following seven common factors were found:

1. Perception
2. Attention/Vigilance
3. Reaction time
4. Learning
5. Decision making
6. Interest and motivation
7. Interpersonal relations

There are three additional common factor areas in Tables 13 and 21, namely

8. Cognition and mentation (which include such factors as judgment, foresight, and channel capacity)
9. Personality (which includes self-confidence, self-sufficiency, composure, and thoroughness)
10. Precise multiple control (which includes sensorimotor skill and motor action)

Two additional factors not common to both tables were deduced, namely:

11. Orientation
12. Stamina.

TABLE 22. Human Factors Related to Flight Safety

Perceptual

1. Visual Perception
2. Visual Acuity - Target Acquisition, Dectection, and Recognition (Collision Avoidance)
3. Color Vision
4. Binocular Vision
5. Night Vision
6. Visual Illusions
7. Eye Movements
8. Depth (Space) Perception
9. Form Perception
10. Motion Perception
11. Scanning - Visual Control
12. Position Error Detection
13. Visual Orientation
14. Spatial Orientation
15. Touch and Tactual Perception
16. Hearing
17. Perception of Motion
18. Perception of Acceleration

Mental

1. Flight Management
2. Instrument Reading (and Comprehension)
3. Cognition
4. Vigilance
5. Rate of Closure Determination
6. Reflection
7. Understanding Verbal Instructions
8. Learning or Acquiring New Material As A Skill
9. Time Sharing
10. Crew Coordination
11. Object Identification
12. Mechanical Principles
13. Recognition
14. Memory (Short Term)
15. Procedural Decisions
16. Concentration of Attention
17. Data Processing
18. Saturation (Information)
19. Information Acquisition
20. Attention
21. Item Recognition
22. Realization of Delayed Reaction
23. Overload
24. Task Oversaturation
25. Central Processing
26. Memory (Long Term)
27. Vocabulary
28. Alertness
29. Code Learning
30. Problem Solving
31. Mental State (Set)
32. Distribution of Attention
33. Vigilance Errors
34. Predisposition Towards Certain Types of Decisions
35. Procedural Errors
36. Comparison of Alternatives
37. Building Relationships
38. Intelligence (General)
39. Decision Making
40. Judgment (Collision Course)
41. Showing Ingenuity
42. Communication
43. Inattention
44. Decode Series of Symbols
45. Finding Relationships
46. Abstraction

Sensorimotor

1. Manual Tracking/Control, Compensatory Tracking
2. Reaction Time (to Act Quickly)
3. Attitude Control
4. Perform Sequential Psychomotor Tasks
5. Precision of Flight Control
6. Kinetic Response Precision
7. Loss of Control
8. Adaptive Control
9. Feedback Control
10. Perceptual Motor Errors
11. Eye-Hand Coordination
12. Precise Multiple Control
13. Psychomotor Skill
14. Frequency Response (of the Human Operator)
15. Complex Performance

Neurophysiological

1. Grip Pressure
2. Neuromuscular Tension
3. Acceleration Tolerance
4. Drowsiness
5. Disorientation/Vertigo
6. Hangover
7. Sleep Deprivation
8. Neuromuscular Control
9. Work Capacity
10. Fatigue
11. Strength (Physical and Mental)
12. Resistance to Boredom

Personality

1. Emotionality
2. Self-Control
3. Affective Behavior
4. Apprehension
5. Ego Involvement
6. Experience vs. Lack of Experience
7. Negligence, Complacency
8. Adaptability
9. Rigidity
10. Responsibility
11. Experience
12. Anger
13. Maturity
14. Temperament
15. Frustration Tolerance
16. Stability
17. Motivation
18. Excess Motivation to Succeed (Ambition)
19. Attitude
20. Overconfidence (Risk Taking)
21. Action Oriented

TABLE 23. Human Factors Related to Flight Safety

(Major Psychophysiological Parameters)

I. Perceptual Factors

A. Visual Perception
B. Tactual Perception
C. Hearing

II. Mental Factors

A. Alertness, Vigilance
B. Attention
C. Cognition
D. Memory
E. Learning
F. General Intelligence
G. Communication
H. Time Sharing

III. Sensorimotor Factors

A. Reaction Time
B. Eye-Hand Coordination
C. Manual Control, Tracking
D. Frequency Response
E. Complex Performance

IV. Neurophysiological Factors

A. Neuromuscular Transmission
B. Neuromuscular Tension
C. Acceleration Tolerance
D. Work Capacity
E. Stress and Fatigue Tolerance

V. Personality Factors

A. Motivation
B. Temperament
C. Personality Structure
D. Attitude, Interest, Morale
E. Experience

It is interesting to note that the analysis of the human errors involved in aircraft accidents yielded several additional factors and a greater variety of variables than were obtained by the analysis of successful pilot behavior.

Finally, the results of our own taxonomy concerning human factors involved in aircraft accidents as well as those found in successful pilots will be presented. The survey of the pertinent literature previously presented in our first report of this series (40) yielded 135 safety related variables as displayed in Table 22. By collapsing the system and by combining the closely related variables, 26 major psychological and psychophysiological factors were obtained as shown in Table 23. They are grouped into five major categories in accordance with the classification system outlined in our earlier study (40).

A comparison of Tables 21 and 23 shows the similarity of the results of these taxonomies. With the exception of the factor "orientation", all other major factors can be found in both tables. By using our technique of combining factors of similar or related characteristics or content, we arrive at the following set of major psychological factors, which appear to be representative of and essential to pilot performance:

1. Perception. This factor includes sensing and perceiving visual, auditory, tactual, and other stimuli, signals, and information as well as the observation, detection, and visualization processes.

2. Attention. This factor includes alertness, vigilance, watch-keeping, span, channel capacity, and time-sharing functions.

3. Reaction. This factor includes reaction time and discrete, serial, and multiple task responses.

4. Orientation. This factor includes bodily, spatial, and geographic orientation.

5. Sensorimotor. This factor includes eye-hand coordination, finger dexterity, speed and accuracy of muscular activities, tracking, and precise multiple control.

6. Stamina. This factor includes body strength, physical, and emotional endurance, acceleration tolerance, work capacity, resourcefulness, and stress and fatigue tolerance.

7. Cognition/Mentation. This factor includes acquisition and processing of information, thinking, concept formation, deductive and inductive reasoning, finding and establishing of relations, judgment, foresight, planning, and problem solving.

8. Experience. This factor includes memory, conditioning, habit formation, situational and personal adjustment, management, and procedural actions.

9. Interpersonal Relations. This factor includes communication, working with others, accepting personal and organizational responsibility, supervision, living and working with others, and crew coordination.

10. Personality. This factor includes self-confidence, self-sufficiency, self-discipline, calmness, composure, risk-taking, thoroughness, attitudes, leadership, and morale.

11. Learning. This factor includes memory functions (both short and long term), remembering written and verbal material, objects, courses of action and relationships; as well as acquiring information from various sources and following procedures based on acquired and learned information.

12. Decision Making. This factor consists of selecting and formulating from a variety of possibilities or a limited number of alternatives a course of action with the intent of executing it. Hence, this factor can be considered independent of cognition/mentation, since decisions can be made for other than logical reasons and contain an intent component beyond the reasoning and judgment state.

In our first report (40) in this series on functional aging, we surveyed studies concerned with age-related psychological functions; a brief review of

the major conclusions we presented in that report seems to be in order here. The review is organized in terms of the twelve factors described above.

1. In general, all sensory threshold sensitivities and the perceptual functions decline with age and complex perception is less accurate and flexible in older people. For visual and auditory perception, the decline involves the peripheral organs and the higher nervous centers. Touch sensation and taste, vibration, and pain sensitivity decrease with increasing age.

2. Surprisingly little is known about the effect of age on alertness, attention, vigilance, and watchkeeping. Bell and Provins (13) found that peripheral attention was affected by aging. One would assume that older people are less alert and attentive than younger ones and lose their vigilance during watchkeeping. Indeed, vigilance falls more rapidly in old persons, but in the early stages of watching for signals, there seems to be no difference between older and younger test subjects (39). The ability to recognize and use structure in attending to redundant stimuli or monotonous tasks also decreases with age. Similarly, attention and time-sharing during task performance declines with age.

3. It has been established beyond doubt that reaction time as a single, isolated factor increases as a function of age. This age-related slowing cannot be attributed to a slowdown of the neural transmission processes but seems to be due mostly to a slower decision making component of the response mechanism. Performance decrements in continuous reaction tasks generally show the same trend and probably are of the same nature. As task complexity increases, the age differences also tend to increase.

4. The orientation (and disorientation) factor is complex and difficult to deal with. A very gross analysis of the conditions under which it has been observed and analyzed in flight accident reports reveal at least two more or less related dimensions, namely spatial orientation and geographic orientation. Ricketson et al. (64) tell us that as to the consequences of disorientation: "these mishaps were catastrophic which seems to indicate that the pilots were unaware of or unable to determine their geographic or spatial orientation."

Recently, Kirkham et al. (45) reviewed the statistics of spatial disorientation in civil aviation accidents. They state that spatial disorientation occurs most often in instrument flight conditions created by rain, fog, clouds, dark nights, and changes from instrument to visual flight and back to IFR conditions. It is also known that excessive head movements which induce strong vestibular stimulation can aggravate the untoward effects by generating all sorts of illusions and vertigo. The pilot can become lost any time the outside visual reference is lost, such as during map readings, changing a radio frequency, searching an approach plate or navigational fix, fuel management, or whatever may distract his attention from outside scanning.

It is well known that spatial disorientation may occur in other than adverse weather conditions; but the most devastating consequences are often weather related.

Without getting too much involved in the basic scientific problems which are still unresolved, it must be pointed out that orientation in flight depends upon the perception of the complex and continually changing patterns of visual stimuli, vestibular input, and other sensory information furnished by various sense modalities. In spatial orientation under conditions of rest, the sensations received through the eyes and the so-called gravireceptors (in particular, the otolithic system) are in accord for the perception of verticality; i.e., one usually knows what is up and down. In contrast, there can be a considerable difference between the impressions furnished by the two sensory systems in the state of motion. This discrepancy may be due to the morphological and functional characteristics of the two systems; one registering photochemically, the other one mechanically.

Although the sensitivity of the vestibular apparatus is important for the accurate orientation of pilots, its function can adversely affect their tolerance to motion because of the close connections with the deep centers of the brain stem. Vestibular stimulation by irregular (as to intensity and direction) accelerations excite well-established reflex mechanisms. This may elicit disturbing processes concerning the central nervous control of the physical equilibrium resulting in disorientation, visual and spatial illusions, and perhaps vertigo. According to their latest statistics, Kirkham et al. (45) report that 16 percent of all fatal accidents in general aviation aircraft had spatial disorientation as a cause factor during the period 1968 through 1975.

In contrast, geographic disorientation seems to be quite different from spatial disorientation as to etiology and experience. It also may occur during periods of cockpit involvement or inattention. During VFR procedures, the visual reference is usually provided by the ground pattern, cloud formations or, as in dead-reckoning, by identifying ground features and comparing them with those available from the navigational chart. When these cues are lost or misinterpreted, the pilot may be lost, too. Ricketson et al. (64) found that most of the disorientation events they analyzed occurred in helicopter pilots under VFR clearances, suggesting that pilots expected to maintain visual contact with the ground or horizon. However, the presence of inadequate weather analysis appeared to indicate that atmospheric obscurations occurred, which the pilots should have successfully dealt with, either before or after they were encountered. The airplane cases analyzed had much in common with the helicopter cases in regard to factor and background variables, but they had a higher factor loading on "faulty flight plan" (64). Although general aviation aircraft are "lost" practically every day (but guided to a safe landing by air traffic control), only about 2 percent of fatalities are caused by geographic disorientation. Perhaps this is the reason why so little has been done by psychologists to lift the veil of mystery as to etiology and underlying functions (86).

One of the still open questions concerns the relationship between spatial and geographic orientation. Is there any relationship? Do people who are easily confused about what is up and down also become easily confused about where they are, where they are going, and where other things are? As a matter of fact, of 78 Royal Air Force aviators studied by Benson (14), 36 had false perception of aircraft orientation, 29 had a disordered perception of their relationship to the aircraft or to the ground, and 11 experienced both types of disorientation. Some of these pilots reported a "feeling of detachment and isolation, frequently associated with flight at high altitude during relatively undemanding phases of the flight". This is different from the feeling of being lost and not necessarily related to geographic disorientation which may also occur during short flights at low altitude. The observation in this latter case that the pilot had simply erred and committed a navigational error, does not contribute to the explanation of the phenomenon (32). And there are other problems. Is the ability always to know where one is and where one is going inborn or, as they say today, genetically determined, or is it learned? If learned, is it easily learned or established through an intensive or intricate mental process? Migrating birds or caribou do not have to have a diploma from navigator school. They must be extremely smart to understand celestial navigation. Thus, is the ability to orient oneself within a given environment a matter of establishing direction, time, and space relations between oneself and a set or sets of exterior objects and circumstances, which would put it into the category of logical thinking and mentation, or can it be classified as instinctive behavior? There are, to my knowledge, no definite and generally accepted answers to these questions. There are no accepted ways of measuring orientation ability or skill. An early attempt by German aviation psychologists to test it as part of their pilot selection battery was not successful (39).

Collins (25-28) who studied the phenomenon of spatial disorientation and its implication on pilot performance and certification over a period of 15 years, concluded recently that most of the manifestations of disorientation occur as a result of the normal, rather than the abnormal, functioning of the vestibular system in motion environments and are caused by a lack of visual information about objects fixed relative to Earth. And he continues: "While clearly unhealthy vestibular or equilibrium systems could conceivably increase the likelihood or severity of disruptive (and dangerous) orientation experiences in flight, the majority of orientation-related incidents and fatal accidents in general aviation are probably attributable to normal vestibular functioning coupled with inadequate instrument flying skills and questionable judgment about safe flying conditions." General aviation flying schools appear to have considerable room for improvement in training pilots regarding spatial orientation (27).

In 1977, Booze (19) analyzed the effects of age and experience on general aviation pilots involved in fatal weather-related accidents with spatial disorientation as a cause/factor. His statistics were based on the

TABLE 24. Relationship Between Fatal Disorientation Accidents and Age of the Pilots for the Period From 1970 through 1975 (Rates Per 10,000 Airmen)

Age Group	Population	Frequency	Rate	Annual Rate
20 - 29	258,297	91	3.5	0.58
30 - 39	209,714	167	8.0	1.33
40 - 49	168,886	179	10.5	1.75
50 - 59	89,889	94	10.4	1.73
60 +	16,656	21	12.6	2.10

figures provided by the National Transportation Safety Board for the 6-year period from 1970 through 1975. The results are shown in Table 24 in which, it should be noted, the figures were not corrected for exposure. However, it appears from a preliminary calculation, that such a correction would not change the trend of increased accident rates with the increasing age of the disoriented pilots contained in this table. And age-related changes in vestibular function were reported by Van der Laan (90) in a group of subjects ranging from 2 to 90 years of age.

5. The sensorimotor performance of older subjects was found to be substantially worse than that of the younger ones. The difference was due particularly to the longer time required for discriminating the stimulus and for the decision making process. The older people also responded more slowly when advanced information on signal appearance was available. Functionally, the inferior performance of the elderly on sensorimotor tasks was interpreted as reflecting a change of the general speed factor which underlies most perceptual and neural processes (17).

6. There is an age-related decrease of muscular or mechanical efficiency, physical strength, endurance, and stamina. The cardiovascular reflexes, which adapt the blood circulation to muscular and heavy aerobic work, also seem to be affected. The skeletal-muscle mass decreases with increasing age. Reduced sex hormone production, a decrement of thyroid hormone output, and intracellular changes may also be involved in the physical deterioration of older persons. By far the most frequent change of behavior and stamina is the increased susceptibility of older persons to fatigue. It may reach the extreme by causing the older person to fall asleep on the job or to become almost inoperative while awake. However, fatigue is not a purely physiological reaction, since motivational and situational influences can either enhance or reduce fatigue.

7. One of the best established findings is that there are age differences in intelligence and mental functions, but all mental abilities are not equally affected by age. Primary abilities classified by Horn and Cattell (42) as "primary fluid" which include associative memory, figural relations, intellectual speed, induction, and intellectual level decline with age from the early twenties; whereas the primaries classified as "primarily crystallized", including such items as "ideation fluency, associational fluency, experimental evaluation, mechanical knowledge, verbal comprehension, and number facility" improved at least up to age 61 (42). Most of the "mixed fluid-crystallized abilities", such as "logical evaluation, semantic relations, common word analogies, practical judgment, visualization abilities, and general reasoning" declined after age 21. Fozard and Thomas (38) who conducted many experiments on the effects of age on intelligence, abilities, and skills summarized their findings: "There is some reason to believe that mental abilities will deteriorate as the individual gets past 50, particularly to the extent that tasks are speeded and to the extent that the test is neutral or even interfered with by the individual's previous experience outside the test situation". As task complexity increases, information channel capacity decreases to reach a state of "mental overload" in older persons sooner than in younger ones. Birren (17) believes that "slowness of information processing with age is an issue directly involved in questions about the basis of somatic changes with advancing age".

8. The influence of aging on experience is very difficult to establish. Experience, as it is meant here, includes such functions as memory, learning, conditioning, and habit formation as well as personal and situational adjustment factors. The "limited experience" factor extracted by Ricketson et al. (64) shows only the negative side of the problem. Recently, Booze (18) has explored the relationships between age, experience, and risk through an analysis of aircraft accidents. Booze (18) points out that certain levels of flight experience are required for the various airman ratings accorded by the Federal Aviation Administration. Thus, one assumes that a beneficial effect accrues with greater cumulative experience. However, at some point, cumulative flight experience ceases to be an asset and becomes associated with risk. As seen in the 1974 general aviation accident data presented in Figure 3, accident rates increased with cumulative exposure for all but the highest exposure category where the drop is slight. Overconfidence and lack of vigilance by high-time pilots have been cited as possible contributors to this situation. Airline pilots, on the other hand, have the highest cumulative experience of any group but continue to have low accident rates. As a rule, they use more sophisticated equipment, both aircraft and navigational, and have more professional help while performing their flight tasks. Their preflight planning and the flight routine are likely to be more disciplined.

FAA regulations also require a minimum amount and type of recent flight experience for an airman to be current. Some minimum recent experience is thus considered necessary for the pilot to perform safely in the aviation environment. One might logically extend this argument to the conclusion that the greater the amount of recent experience one has, the safer he or she is

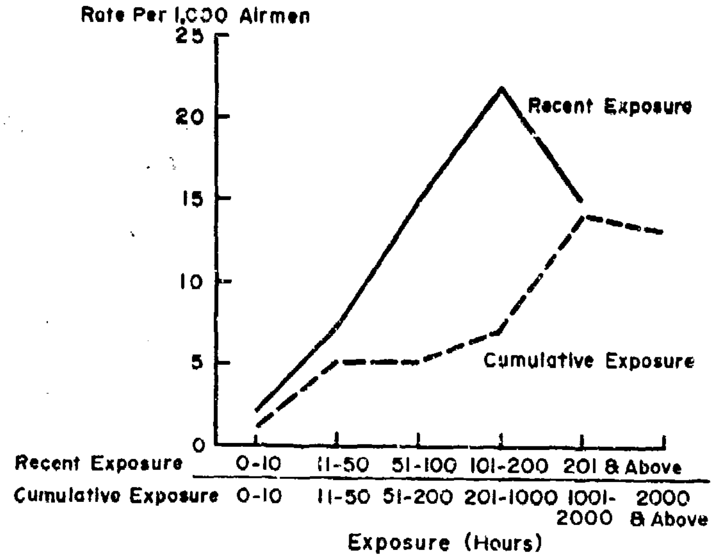

Figure 3. 1974 general aviation accident rates by flight time as reported by Booze (18).

as a pilot. There are accident data available which seem to indicate that the more current a pilot is, the less likely he is to have an accident (93). However, the same patterns that are described for cumulative flight time emerged for recent flight time in the statistical analysis. Greater recent exposure to the general aviation flight environment resulted in a higher degree of risk, as shown in Figure 3. Relative risk is defined by Booze (18) as the ratio of accident rates among those with the characteristic to the accident rate of those without the characteristic, e.g.,

$$\text{Relative risk} = \frac{\text{accident rate among high age airmen}}{\text{accident rate among all other airmen.}}$$

From the literature and preceding discussion, it appears that age and flight experience are important variables in regard to aviation accidents. Exposure to the environment is obviously necessary to incur risk of accident. This fact is, and always has been, indisputable. Hence, general aviation accident rates increased in 1974 with an increase in cumulative flight experience for the total population as shown in Figure 4. When the cumulative exposure intervals in Figure 4 are considered separately, some increase in accident experience with age is also noted for low experience levels. However, for higher cumulative exposure, younger ages had much higher rates. Large numbers of airmen in lower age groups at lower exposure intervals tended to weight the total rates and produced low overall rates for younger ages: Well over one-half of the airman population had cumulative experience of 200 hours or less, while only one-third of the accidents were in this interval.

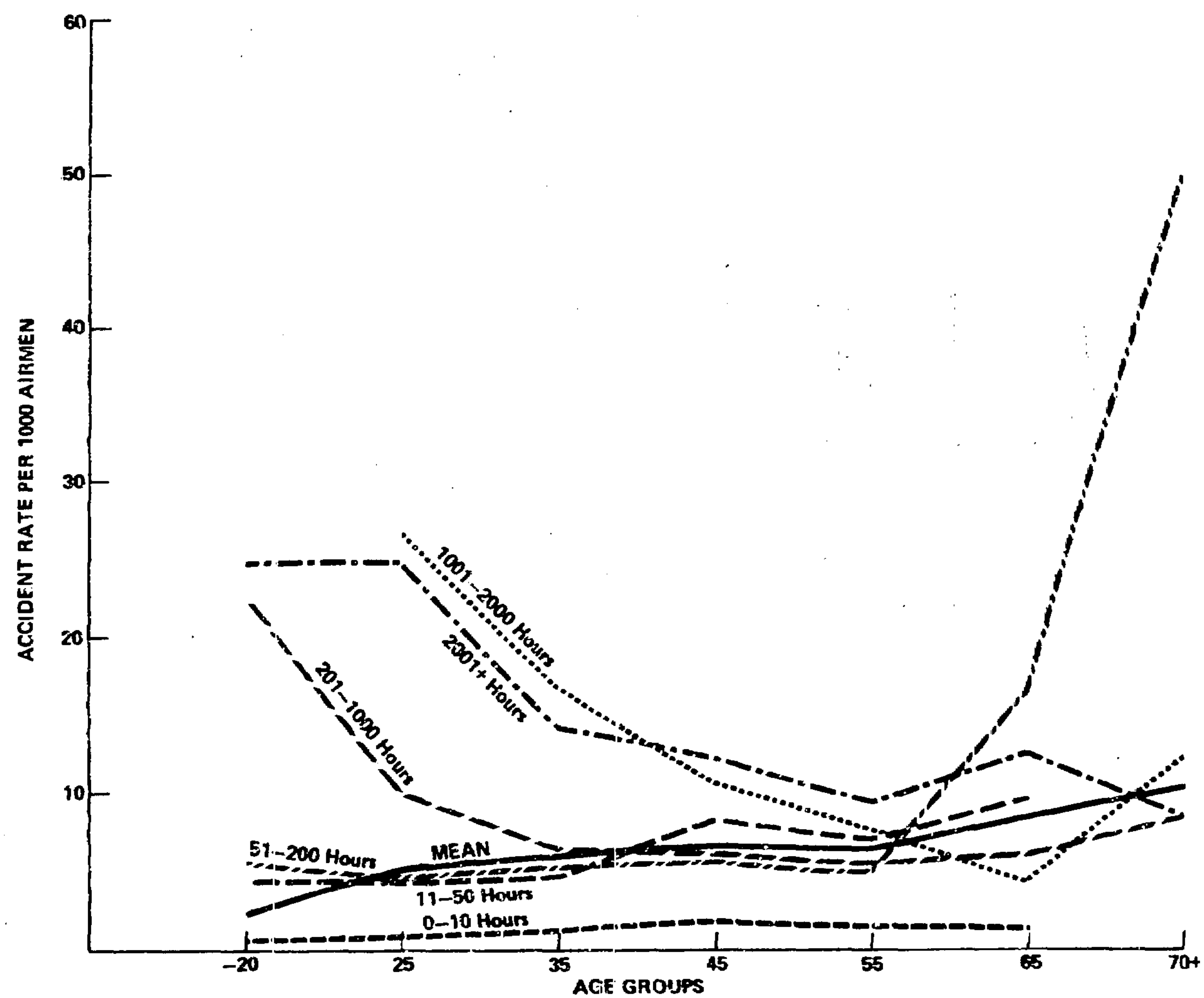

Figure 4. General aviation accidents and age for various amounts of experience (flight hours) as reported by Booze (18).

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TABLE 25. Relative Risks Associated With Cumulative Experience and Age as Determined by Booze (18)

Risk Factors	Relative Risk
High age only	1.2
High exposure only	3.1
High age and high exposure	1.4
High age and low exposure	0.8
Low age and high exposure	2.7
Low age and low exposure	0.3
Within low ages: high vs. low exposure	3.4
Within high ages: high vs. low exposure	1.6
Within high exposure: high vs. low age	0.8
Within low exposure: high vs. low age	1.6

When the age intervals are considered separately, a pattern of increasing rates with increased exposure is seen for all age intervals through 50-59. The trend for age intervals 60 and above is not so clear, with higher rates occurring at lower exposure intervals.

For purposes of the current analysis, the ratio of accident rates (relative risk) has been computed for the several pertinent comparison possibilities. The results are summarized in Table 25. High exposure is seen to produce highest risk when considered separately and when combined with younger ages. For higher ages, increased cumulative exposure does not appear to be so important.

Whether one considers total experience or recent experience, the implication of increased exposure is apparent. Furthermore, recent experience appears to be more important than cumulative experience as a risk factor, according to the analyses performed by Booze (18).

Some accepted notions about the relationship of greater accident rate with age have been shown to be erroneous when exposure is added to the equation for risk determination. Younger ages have been found to have higher general aviation accident rates at both high cumulative and recent experience levels. Although younger ages were very broadly defined by Booze (18) his finding is consistent with motor vehicle accident rates; however, an assumed causal factor in motor vehicle accidents is lack of experience. It seems that other factors characteristic of younger ages must be involved in general aviation accidents.

9. Decision making per se has not received much attention lately in the research on aging. One can speculate that the reason for this lack of interest may be brought about by the gerontologists' reluctance to look at it as a discrete factor but treat it either as part of the mental function complex or as part of the human response process. One element of this complex, the choice of strategies, has been experimentally studied. Sanford and Maule (69) found no differences between young and old subjects in regard to optimum strategy, but the old generally performed more poorly than the young. In an earlier two-choice experiment, Sanford et al. (68) observed that decision making ability was impaired with age and that the older group responded slower than the younger group. But this delay could very well have been caused by the perceptual-motor component. In sum, decision making seems to be age-related; and the difficulty in making fast decisions may reflect the difficulty in maintaining speed and control of cognitive activity with progressing age.

10. The capacity for learning decreases with age. So does the ability to recall previously learned material. "Although conceptually different, learning and memory seem to be inextricably linked--how can one remember something which has never been learned?" (71). Hence, this parallel decrease of the two closely related functions is understandable. Many experiments have been conducted in this area, and the results have been interpreted in various ways. Schaie and Gribbin (71) have summarized the findings and pointed out the different viewpoints. They have not considered, however, the close relationship among memory, learning, and experience, which is logically established by the fact that the latter is accumulated and used through the process of learning and the ability to recall identical or similar conditions, situations, objects, persons, circumstances, and relationships. There are also tie-ins with the acquisition, processing, and handling of information and thus with the overload problem mentioned before. Attempts to improve learning and memory in the aged by means of biochemical mediators have not shown consistent results (71).

11. Changes in interpersonal relationships, whether in flight leadership or general contact with co-workers, represent a small but seemingly important number of the critical behaviors reported in a study of the effects of aging on aircrew performance (76). In work that requires continual close cooperation with other crew members, interpersonal relationships probably often contribute more to success or failure than a minor deviation from acceptable performance in an individual's task. Airmen who were found to show adverse signs of aging also displayed a tendency toward poorer relationships with their co-workers and a tendency toward lower morale and less satisfactory adjustment to their jobs.

12. The personality factor is treated here as a "remnant" of the factor analytical approaches (in particular the one followed by Ricketson et al. (64)) and contains the highest degree of ambiguity and uncertainty of the factors identified in this study. It includes such variables as overconfidence, self-discipline, apprehension, mood (tension, anxiety, anger, depression),

consciousness, maturity, risk-taking, rigidity, and adaptability, that were found in the various taxonomies but are not listed here as separate factors. Motivation, experience, psychophysiological stability (stamina), even learning, decision making, and personal relations are personality-dependent variables, but they were identified as independent factors in this context.

Only a few of the personality variables were found to be age-related. For example, a significant decrease in all measures of flexibility and a significant increase in all measures of behavioral rigidity have been reported. Lowered impulsivity and emotionality are frequently associated with advancing age. Personality in its structural sense is remarkably stable during the adult years in most respects, and responsibility as a trait or behavior seems to increase at least up to age sixty. Individuals who are older now are more likely to be introverted, more controlled, less energetic, lower on surgency, and have lower needs for achievement than people who are now young (38).

In summary, it appears that all of the twelve factors, which were extracted or derived from the various task taxonomies and considered to be essential for safe pilot performance, are age-related in one way or another. The scientific "background" of these factors has been well established in most cases, and the operational implications are known. The two factors which deserve more exploration are "experience" and "orientation". Particularly, in the latter area, the etiology and the constituent psychological functions and mechanisms which disrupt the pilot's awareness of his position, location, and movement in space/time and thus cause disorientation, deserve further exploration. We need to know why a pilot loses his knowledge of attitude, altitude, position, and direction while flying VFR or IFR, although reliable visual cues from the ground or from his instruments are at his disposal and his vestibular sensory input is intact.

V. Pilot Selection and Training.

Pilot performance has been extensively assessed, measured, and validated in conjunction with pilot selection procedures. These procedures have changed, however, in the recent past, and there is still a lot of experimenting, modeling, and evaluating in progress in order to improve the existing procedures. Experience has shown that pilot selection is a dynamic process that usually starts along academic lines when the candidates are screened and tested in order to select out the apparently undesired ones and to determine the chances of the accepted ones to successfully complete the training. The process then continues as a more or less empirical selection consisting of eliminating, rating, and grading the flight students at least up to the advanced training phase.

It is not intended to discuss here the validity and reliability of the selection and training programs for military or civilian aviators. Selection procedures of various kinds are being used today in many countries and by different military and civilian organizations. Psychological tests are an

integral part of practically all of them. The purpose of this final part of the present report is to discuss some of the attempts made by selection and training specialists to analyze the correlations between the psychological test scores and measures of performance or actual pilot proficiency, in order to obtain information about the psychological functions and factors which contribute to training success. As we will see, the direct correlations between the test scores and final success as a pilot are not very high, but they are useful. The hypothesis is that although the correlations between the individual tests and the selection criteria may be small, together they are likely to produce a multiple prediction of successful pilot performance. Moreover, it is generally assumed that the greater the overlap between the testing situation and the measure of success, the more likely the test will have predictive value.

The pilot indoctrination program (PIP) of the United States Air Force also identifies those cadets at the Air Force Academy who possess the basic aptitude to become Air Force pilots. The purpose of this program is to provide identification, at the least expensive time, of those applicants who fail to meet the aptitude/attitude requirements necessary to complete undergraduate pilot training. First of all, an applicant must attain a 25th percentile (or higher) on the pilot composite and a minimum of the 10th percentile on the navigator-technical composite of the Air Force Officer Qualifying Test (AFOQT) (53,54). The AFOQT evolved from the Aircrew Classification Batteries of World War II and the Aviation - Cadet Officer - Candidate Qualifying Test of 1950. It is based ultimately on analyses of the tasks required of student pilots, navigators, and officers. The 13 subtests are briefly described below:

Quantitative Aptitude consists of items involving general mathematics, arithmetic, reasoning, and interpretation of data read from tables and graphs.

Verbal Aptitude consists of items pertaining to vocabulary, verbal anologies, reading comprehension, and understanding of the background for world events.

Officer Biographical Inventory consists of items pertaining to past experiences, preferences, and personality characteristics known to be related to success in officer training.

Scale Reading consists of items in which readings are taken of various printed dials and gauges. Many of the items require fine discriminations on nonlinear scales.

Aerial Landmarks consists of pairs of photographs of terrain as seen from different positions of an aircraft in flight. Landmarks indicated on one photograph are to be identified on the other.

General Science consists of items related to the basic principles of physical science. The emphasis is on physics, but other sciences are also represented.

Mechanical Information consists of items pertaining to the construction, use, and maintenance of machinery. Some of the items are concerned with the use of tools.

Mechanical Principles consists of diagrams of two complex apparatus. Understanding of how the apparatus operates, or the consequences of operating it in a specified manner, is required.

Pilot Biographical Inventory consists of items pertaining to background experiences related to success in pilot training.

Aviation Information consists of semi-technical items related to various types of aircraft, components of aircraft, and operations involving aircraft.

Visualization of Maneuvers consists of items requiring identification of the silhouette which expresses the attitude of an aircraft in flight after executing a verbally described maneuver.

Instrument Comprehension consists of items similar to those in Visualization of Maneuvers except that the maneuvers are indicated by reading of a compass and artificial horizon.

Stick and Rudder Orientation consists of sets of photographs of terrain as seen from an aircraft executing a maneuver. The proper manipulation of the control stick and rudder bar to accomplish the maneuver must be indicated.

Miller's (53) development and standardization effort of the AFOQT form M shows examples of difficulty levels and weight assignments for the various test applications.

The AFOQT is periodically revised to incorporate improvements and changes dictated by an ongoing program of psychometric research. An example of this effort is the development of a new navigator - technical composite as described in Valentine's (89) report of 1977. The analysis of results obtained from 45 noncognitive test scales and 17 experimental cognitive tests, along with AFOQT data, against training success indicated that, of the noncognitive materials, only the Personality Research Form had unique validity and was recommended for further study. The report (89) also shows the many possibilities for developing psychological tests for the measurement of aptitudes important in the selection of officers for pilot and navigator training.

The use of psychomotor tests in the U.S. Air Force pilot selection program was discontinued in the early 1950's, although it was generally acknowledged that the assessment of sensorimotor ability had validity for predicting elimination from pilot training beyond that obtained from paper-and-pencil tests. Therefore, two psychomotor tests, namely the Two-Hand Coordination and the Complex Coordination tests, were validated as predictors of pilot training success (51). The multiple correlation of complex coordination with and without AFOQT test scores and three pilot training criteria, namely

graduation, flying training deficiency (FTD), and self-initiated elimination (SIE) during the training period, are shown in Table 26. The correlations are above 0.5 without the AFOQT scores, and they exceed 0.6 when these scores are added. The authors, therefore, conclude that inclusion of complex coordination testing would improve the selection of successful student pilots.

Table 26. Multiple Correlation of Complex Coordination and AFOQT Scores Against Three Pilot Training Criteria. Data (N=92) Are From McGrevy and Valentine (51)

Predictor Tests	Number of Predictors	Trial	Correlations Graduation	FTD	FTD/SIE
Complex Coordination	15	1	.43	.50	.43
Complex Coordination plus AFOQT	20	1	.50	.56	.51
Complex Coordination	15	2	.56*	.43	.55*
Complex Coordination plus AFOQT	20	2	.62*	.50	.61*
Complex Coordination	15	3	.55*	.44	.55*
Complex Coordination plus AFOQT	20	3	.60*	.54	.61*
Complex Coordination	15	4	.47	.41	.45
Complex Coordination plus AFOQT	20	4	.51	.47	.51
Complex Coordination	15	5	.51	.47	.49
Complex Coordination plus AFOQT	20	5	.57	.53	.55

*Significant beyond .05 level.

Lohmann (49) summarized the findings of an analysis of abilities and personality traits associated with successful completion of Air Force undergraduate pilot training as follows:

> "Additional research done in a military environment has indicated that four abilities are considered important for successful completion of undergraduate pilot training (UPT). These are:
>
> 1. Intelligence measured by tests of judgment and intellectual ability,
> 2. Spatial apperception measured by alertness, observation, and speed of perception,
> 3. Mechanical comprehension and coordination measured by coordination and visual motor skill tests, and
> 4. Academic achievement measured by information tests."

He also states (49) that "the appropriate traits, as opposed to abilities, in the determination of successful performance as a pilot, are less well defined." However, he singles out three such traits as important, namely

1. aggressiveness as essential to the military pilot,
2. anxiety proneness as being negatively related to flight training success, and

3. motivation which can be assessed by the amount of effort expanded on a particular task.

And he concludes (49):

> "In summary, previous research has shown that abilities and traits are significant influences on performance in learning situations and in flying careers."

In Europe, particularly within the western European nations, the American "Stanine" test battery developed during World War II has prevailed more or less unchanged for the selection of military pilot candidates (87). In short, the psychological tests comprise general information concerning aviation, arithmetic and numerical operations, interpretation of flight instruments, verbal comprehension, spatial orientation by means of aerial photographs, dial and table reading, mechanical principles, reaction time measurements, and rudder control. From their pilot selection matrix, French aviation psychologists extracted the following factors, which they believe play a dominant role for success in pilot training (56):

1. Psychomotor Ability. Based on the results of the rudder control test, this factor had the highest correlation with the pass/fail criterion from primary flight training.

2. Interest in Aviation. As determined from the students' knowledge about aviation.

3. Mechanical Comprehension.

4. Space Perception and Orientation. This factor apparently involves spatial as well as geographic orientation. From a logical point of view, the use of aerial photographs has more face validity than scientific justification because of the large number of unknown variables that obscure the nature of this factor.

5. Verbal Comprehension.

6. Numerical Operations.

It was pointed out later (80) in a factorial analysis of a different kind that the classical triad of mechanical, numerical, and verbal abilities has survived until now, that the spatial manipulation factors should be emphasized for pilots, and that perceptual flexibility factors should be explored further specifically in regard to helicopter performance.

Teerink (84) and Rondon (65) validated a psychological selection program conducted over a period of 10 years in the Royal Dutch Air Force and published the results in two related papers. By correlating four groups of 32 variables, which included such items as level of education, results of

personal interviews, peer ratings, previous experience as a pilot, and the scores of psychological tests, the authors obtained rather constant interrelationships, some of which were of questionable validity, however. By validating them against the pass/fail dichotomy of flight training, we obtained the following factors of consequence:

Instrument interpretation	Flight position
Rudder control	Complex Coordination
Aviation information	Visualization of maneuvers
Pilot experience	Mechanical comprehension
Sensorimotor ability	Sense of reality

When the results of other research conducted by the same scientists were considered, there emerged two more factors, namely, peer rating of "prominence" and flying grade.

The United States Navy has conducted several research studies concerning the selection and training relationship of aircraft pilots. In the initial selection process, the candidates are tested in five major areas, such as intelligence, physical fitness, psychomotor abilities, mechanical comprehension, and background information. If the candidate is accepted, he faces four major steps of training as a naval aviator: Primary training, basic training, advanced training, and the replacement air group (RAG) training program. Most research in this area has been devoted to the isolation of abilities and skills and the prediction of success at the undergraduate level of training. For example, Bair et al. (7) found that the best prediction of preflight training performance was obtained with academic aptitude tests, but that basic and advanced flight grades were most predictable through measurements of perceptual abilities.

Bale et al. (9) identified predictors of a pass/fail criterion at the RAG phase of training and recommended a continuous-type of performance testing at the various stages of advancement. Three years later, the same authors published a paper (8) concerning the relationship between performance in the undergraduate phases of naval aviation training and the RAG phase. The proportions of explained criterion variance among the various grades clustered in terms of meaningful categories or "training elements" are shown in Table 27. These categories were obtained through an analysis of previously defined training requirements (8). It can be seen that those measurements of "mission/combat skills" accounted for the largest amount of explained variance; whereas selection test scores and the results of academic tests and physical training did not contribute much to the total. Bale et al. calculated the proportions of explained criterion variance displayed in Table 27 by using a forcing function in successive computations of R in a multiple correlation test. This technique forced grades sequentially by cluster into the R-computations so that percentages of explained variance could be identified (8).

TABLE 27. Contribution of Various Elements of Aviation Training to Prediction of Satisfactoriness Clustered by Type of Activity (Adapted from Bale, Rickus, and Ambler (8))

Training element	Proportion of explained variance
Selection tests	.062
Academic training	.095
Physical training	.012
Flight skills	.278
Instrument skills	.191
Mission/combat skills	.362
Total	1.000

TABLE 28. Summary of Zero-Order Correlations Between Item Scores and Rag Grades as Determined by Shannon and Waag (74)

		Correlations With:	
Item	Stage	Stage Grade	Total Grade
Headwork	PF	.510	.035
Basic Airwork	PF	.699	.276
Landings	PF	.655	.194
VFR G/S Control	PF	.653	.244
Maneuvers	PF	.459	.108
Altitude Control	PS	.434	.302
Headwork	PS	.291	.121
Basic Airwork	PS	.255	.255
Aggressiveness	PT	.731	.447
Offensive ACM	PT	.867	.440
Lookout Doctrine	PT	.618	.265
Headwork	PT	.612	.217
Basic Airwork	PT	.639	.410
Speed Control	FMLP/CQ	.579	.611
Glide Slope Control	FMLP/CQ	.645	.549
Scan	FMLP/CQ	.534	.439
Power/Nose Control	FMLP/CQ	.695	.646

Brictson et al. (21) used four selection test scores obtained from the aviation qualification tests, mechanical comprehension test, apperception tests, and a biographical inventory to predict carrier landing performance of U.S. Navy pilots. While the psychological scores previously obtained correlated only slightly with the operational criterion measures, the highest correlations indeed were found by using a composite score which included all available test and training data. An additional operational measuring technique for F-4 fighter pilots was developed by Shannon and Waag (74). These investigators isolated the most critical skills and procedures within each of the stages comprising RAG training and then selected a set of graded items as shown in Table 28. As was the case in Brictson's study, the highest correlations were obtained between the operational items and the RAG grades (75).

In another approach to define and measure the abilities and skills which are associated with pilot proficiency, Stanley (80) used the critical incident technique on a group of combat experienced naval aviators. An interview and a rating form were designed and used by five independent raters who were Navy attack or fighter pilots and had a certain degree of combat experience. A list of eight categories of effective behavior, and nine categories of ineffective behavior was available to these raters. The list was based on the results of the interviews that preceded the rating procedure.

Behavioral factors, functions, and rank orders of the total ratings are shown in Table 29. Some of the ratings characterize effective, others ineffective pilot behavior to a certain degree. For example, the ability to function under stress and to communicate efficiently seems to be characteristic of efficient pilot behavior, but the lack of these abilities is not necessarily indicative of inefficient behavior. The unsuccessful pilot seems to be more characterized by poor capacity for making decisions, lack of flight or mission preparation, and excessive concern with his self-image. The remaining categories, namely situation awareness, procedural abilities and skills, determination or fixation, the extent of confidence, and the ability to relate to the mission were found to be almost equally distributed in effective and ineffective combat behavior (80).

Ambler and Smith (4) developed an automated system of test construction for the U.S. Navy, that involved a large bank of data on psychological and operational test items. Their study examined test material which, with the exception of a biographical inventory, covered a wide spectrum of cognitive abilities or functions. This effort was aimed at determining what kind of test items would be most relevant for use in screening and classification of current aviation specialties, and to establish guidelines for acquiring input data for the test item bank.

Ambler and Smith (4) obtained the scores for the seven tests of the Guilford Zimmerman Aptitude Survey, the Hidden Figure Test, and the four tests of the Navy and Marine Corps aviation selection battery from approximately 1,700 aviation trainees. The trainees were divided into eleven mutually exclusive groups which reflected either successful or nonsuccessful training performance.

TABLE 29. Rank Ordering of the Total Ratings of

Behavioral Factors Obtained by Stanley (80)

Behavioral Factors	RATING Effective	Ineffective	Total	Rank
Situation Awareness	85.5	76.7	162.2	1
Procedure Ability	77.6	76.2	153.8	2
Decision Making Capacity	39.0	113.5	152.5	3
Determination/ Fixation	68.0	56.9	124.9	4
Stress Capacity	87.3	19.1	106.4	5
Lack of Preparation	--	38.2	38.2	6
Excessive Concern with Self-Image	--	28.6	28.6	7
Self-Confidence/ Overconfidence	9.7	19.2	26.9	8
Concern	9.7	19.0	26.7	9
Communication	19.4	--	19.4	10

A series of eight factor analyses was performed by means of principal axis solution. The first analysis involved the total group with the eleven-category special criterion. The remaining ones used various combinations of subgroups and criteria. In general, six factors were identified although only five emerged for certain subgroup combinations. Table 30 shows the six factors and the clustering of test variables that consistently, across groups, contributed to their identification and label. The "P" label means the primary or highest factor loading within a factor and the "s" means secondary or moderate factor loadings.

The six factors identified and interpreted by Ambler and Smith (4) are:

Factor I: "Mechanical" (M). The Mechanical Knowledge and Mechanical Comprehension Tests loaded the highest on Factor I. The Spatial Visualization Test tended to load here also but with smaller loading values than the two with the "P" level.

Factor II: "Spatial Manipulation" (SM) was defined by the Spatial Orientation, the Spatial Visualization, and the Spatial Apperception Tests. The hidden figures and the Mechanical Comprehension Tests were secondary contributors.

Factor III: "Perceptual Flexibility" (PF). Here the primaries were Numerical Operations, Perceptual Speed, and Hidden Figures. The secondaries were Spatial Orientation and Spatial Visualization.

Factor IV: "Verbal Intelligence" (VI). Verbal Comprehension and the Aviation Qualification Tests (AQT) were strong here with a little help from General Reasoning.

TABLE 30. Factor Loading Patterns of the Various Tests for Each of Six Factors as Derived by Ambler and Smith (4)

(P = primary or highest factor loadings; s = secondary or moderate factor loadings)

Test	Factors					
	I Mechanical	II Spatial Manipulation	III Perceptual Flexibility	IV Verbal Intelligence	V Numerical Intelligence	VI Flight Motivation
Verbal Comprehension				P		
General Reasoning				s	P	
Numerical Operations			P		s	
Perceptual Speed			P			
Spatial Orientation		P	s			
Spatial Visualization	s	P	s			
Mechanical Knowledge	P					s
Hidden Figures		s	P			
Aviation Qualification (AQT)				P	P	
Mechanical Comprehension (MCT)	P	s			s	
Spatial Apperception (SAT)		P				
Biographical Inventory (BI)						P

Factor V: "Numerical Intelligence" (NI). General Reasoning and the Aviation Qualification Test defined the factor with secondary support from Numerical Operations and Mechanical Comprehension. The General Reasoning Test presents verbally problems involving arithmetic solutions; there is evidence that it contributes to both Factors IV and V. The AQT has both verbal and mathematical content.

Factor VI: "Flight Motivation" (FM) was defined principally by the Navy's Biographical Inventory (BI), which is a non-cognitive test empirically constructed as a correlate of success in flight as opposed to failure or voluntary withdrawal. Mechanical Knowledge was the secondary factor here which probably is a reflection of mechanical or technical interest.

In addition to the identification of factors, the potential discriminatory validity of each factor was defined for the Naval Flight Officer (NFO) and pilot programs, and for various specialities within these programs.

A behavioral taxonomy of tasks and skills involved in U.S. Air Force undergraduate pilot training (UPT) was done by Meyer et al. (52) in 1973-74. The descriptions of flying tasks provided by a "surface analysis" permitted the authors to identify the skills needed for the performance of these tasks. To structure their surface analysis, a simple model of the flying process was

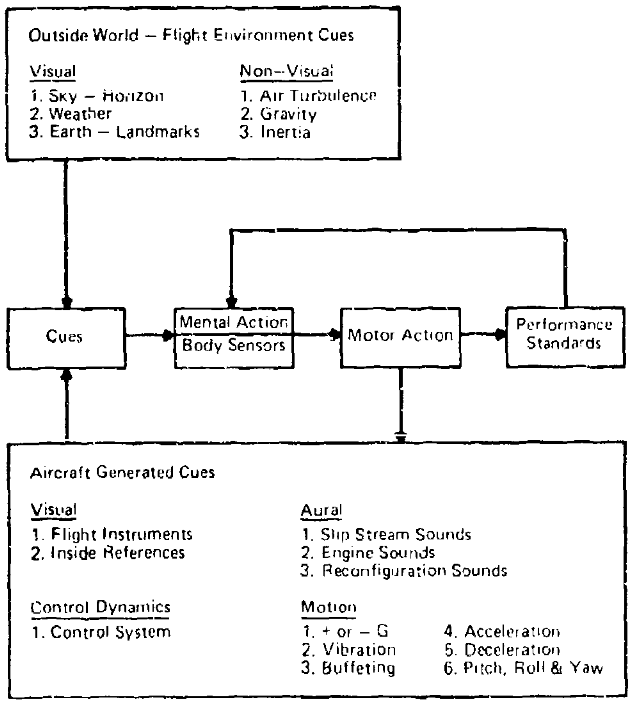

Figure 5. The pilot-aircraft paradigm developed by Meyer, Laveson and Weissman (52).

constructed (Figure 5). The human element in the model is represented by a chain of cues and actions, where: "Cues" (C) represent the environmental and system stimuli which excite the sensory systems; "Mental Actions" (MA) represent the cognition processes initiated by perceived stimulus cues, preceding motor actions; and "Motor Actions" (MO) represent the physical actions resulting in aircraft control movement. Meyer et al. (52) considered this sequence of Cues - Mental Action - Motor Action (C-ME-MO) as a reasonable format for analyzing tasks, and it was adopted by the authors throughout their surface task analysis. The main concept of the analysis was that flying tasks can be categorized into fundamental (F), composite (Cp), and continuous (Ct) transitional processes.

By the application of simple rules, those behavioral elements which were required for the performance of flying tasks involving some basic skills were extracted from the taxonomy. The rules were developed specifically for this application after careful examination of many behavioral classification categories developed by previous researchers. A basic skill was defined as the behavioral elements that are required to perform each task sequence. The initial division in the classification methodology followed the surface analysis structure and identified the parts of a skill in terms of a Cue, Mental Action, or Motor Action segment. Each of these segments was further subdivided into specific behavioral elements and descriptors. Table 31 shows the final form of the categories available for each part of a skill determined through many iterations.

Figure 6 is a schematic representation of the landing training task. It was thought to incorporate about 80 percent of the landing skills including the pertinent go-around skills the student was supposed to possess. The authors concluded that the taxonomy provided a useful tool for the analysis of this and other flying tasks. It apparently furnished specific information needed to the understanding of flying skill requirements.

In a study to predict and corroborate flight performance of Italian flight students, Ramacci (63) compared the results of psychological, physiological, and operational assessments of a group of students made on the ground and in the air. The psychological examination included numerical operations, reaction time measurements, psychomotor coordination, intelligence tests, and an interview. The operational test consisted of performance assessment in flight simulators and during flight maneuvers in aircraft. There was a modest correlation between the final flight evaluation and the psychological test scores, but the closest agreement was found between inflight performance and the results of the final operational test (63).

As is the case with most studies of personality characteristics of aviators, a recent assessment of the factors involved was based on a clinical instead of an experimental approach. For the benefit of psychiatric pilot selection, Christy (29) pointed out that the motivation and conflicts of

Table 31. Behavioral Element Categories and Classification Rules Developed by Meyer, Laveson, and Weisman (52)

1. CUES			
KIND	COMPLEXITY	TOTAL INPUTS	
Visual.........V	1-Cue........1-C	T-1	T-5
Aural..........A	2-Cues.......2-C	T-2	T-6
Control........C	3-Cues.......3-C	T-3	T-7
Motion.........M	4-Cues.......4-C	T-4	T-8...etc.

2. MENTAL ACTION		
COMPLEXITY	INFORMATION PROCESSING	DECISION PROCESSING
1st. Level....L-1	Specific Cue Processing....SC	Simple Judgement......SJ
2nd. Level....L-2	Memory Recall Processing....RP	
3rd. Level....L-3	Multi-Cue Processing....MC	Complex Judgement......CJ
4th. Level....L-4	Iterative Processing....IP	

3. MOTOR ACTION		
CONTINUITY	CONTROL OUTPUT	COMPLEXITY
Establish Attitude.....EA	Aileron..........AI	1st. Rank.......R-1
	Elevator.........EL	2nd. Rank.......R-2
	Rudder...........RU	
Establish Rate of Attitude Change.......ER	Throttle.........TH	3rd. Rank.......R-3
	Trim.............TR	4th. Rank.......R-4
	Other Outputs....OO Speed Brakes - Gear Wheel Brakes - Flaps	5th. Rank.......R-5

Rules for Cue Classification

1. Identify all of the different kinds of cues used in the task sequence.

2. Determine the complexity of the cues. Complexity is determined by counting the different kinds of cues.

3. Determine the total number of cue inputs. This total is determined by totaling the number of individual cues found within each of the cues.

Rules for Mental Action Classification

1. Determine the complexity of the mental action involved. Complexity is determined by noting the number of kinds of cues as found in the cues rule No. 2 above (Complexity), counting the number of different control and discrete actions in the motor action column of the task sequence, and identifying the proper category from the following combinations:

One Cue	-	Zero or one control action
One or more Cues	-	Non-coordinated control actions
One or more Cues	-	Coordinated control actions
Two or more Cues	-	Both coordinated and non-coordinated control actions

2. Select the appropriate information processing category. Compare the action verb used by the analyst in the mental action column of the task sequence with these definitions:

Specific Cue Processing	-	Observes
Memory Recall Processing	-	Anticipates
Multi-Cue Processing	-	Determines
Iterative Processing	-	Sustains

3. Determine if the mental action entry requires a simple judgment or a complex judgment.

A decision based on a specific cue, fact, or procedure is a simple judgment.

A decision based on estimation or interpretation is a complex judgment.

Rules for Motor Action Classification

1. Decide if the motor action results in the establishment of a stable attitude or produces a rate of attitude change.

2. Identify all control outputs made by the pilot in this task sequence.

3. Indicate the complexity of the motor actions taken by the pilot. Complexity is determined by selecting the appropriate complexity rank from the following list:

1st Rank	-	One output
2nd Rank	-	Non-coordinated outputs
3rd Rank	-	Two coordinated outputs
4th Rank	-	Three coordinated outputs
5th Rank	-	Coordinated and non-coordinated outputs

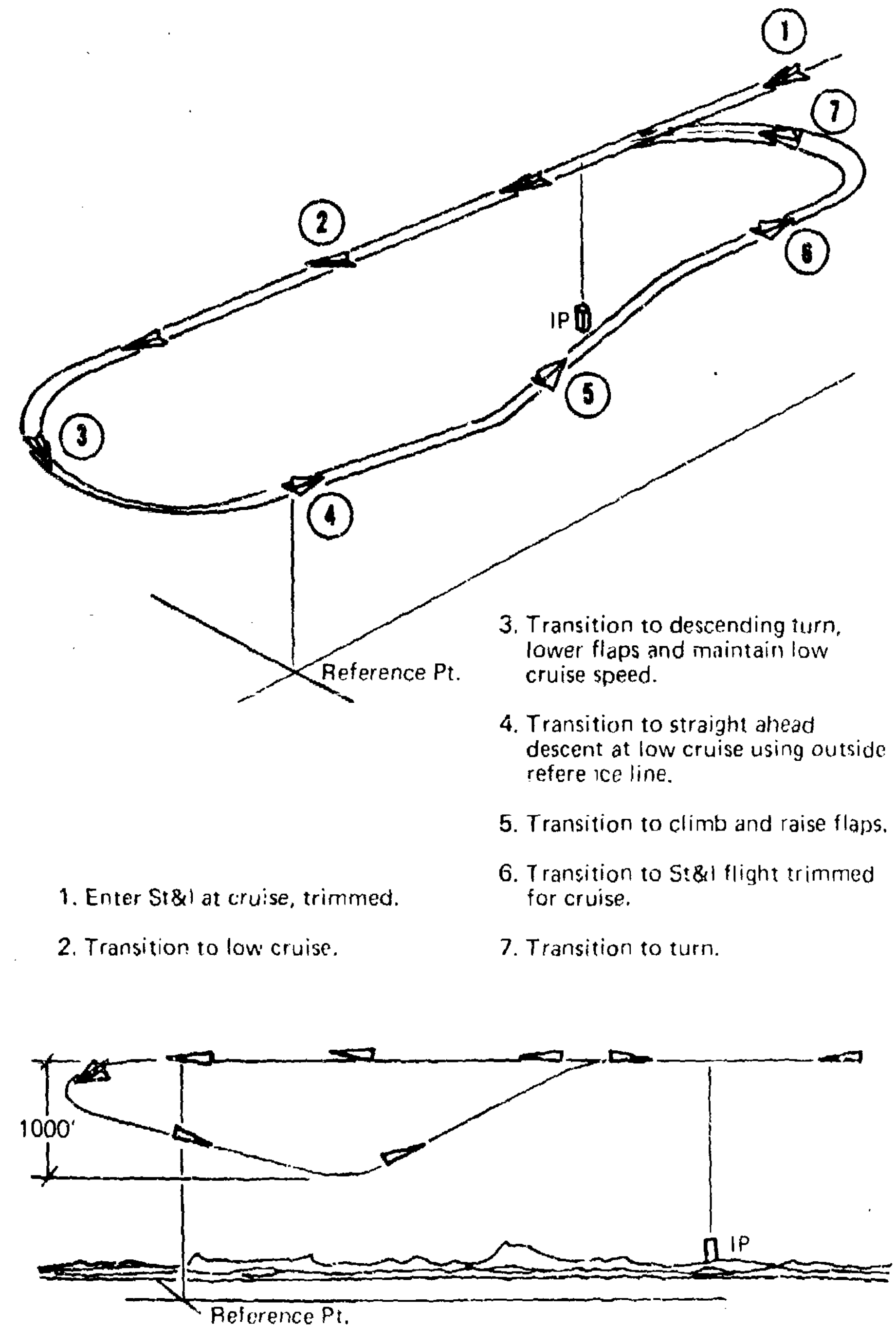

Figure 6. The landing training task as depicted by Meyer et al. (52).

flying involve many personality characteristics and traits which need careful evaluation. He considered the mature, motivated, well-integrated individual who has a good self-image, is curious, active, and able to cope with the demands of life, as the achiever of adequate or better pilot performance. He accepted a rather rigid personality, up to a point, as a positive asset in a flying career; but he scored the compulsive, perfectionistic person as one who will fail in this career. By putting words and meaning together, we arrive at the following desired personality traits:

1. Intelligence	5. Rigidity or emotional stability
2. Maturity	6. Alertness
3. Adaptability	7. Stress resistance
4. Independence	8. Motivation to fly.

Christy (29) also pointed out that with aging or psychosocial stress, the pilot who is marginal in ability and motivation may change toward the negative: Decompensation of fear and anxieties with breakdown of personality and psychological defenses, loss of self-esteem and relationship with others, may occur during the later years and threaten the pilot's proficiency.

Recent efforts made by various investigators to identify and measure the psychological factors which were thought to be essential for success or failure in pilot selection and training were surveyed in the preceding paragraphs. By using examples from the military services, it was shown that it is not only possible to identify such factors, but also to delineate the methods or techniques, which have been applied successfully for the isolation, testing, and quantification of such factors, abilities, and skills. The findings suggest that skills can be identified and procedures can be developed which are effective in selecting potentially successful flight students and highly predictive of future pilot performance. The twelve factors identified earlier as essential to flight safety also appear to be associated with the selection and training criteria. In addition, two more factors can be isolated from these studies:

13. Mechanical Aptitude. This factor includes mechanical comprehension, handling tools and equipment, visualization of mechanical relations, detecting and locating malfunctions in instruments, and fabricating, assembling, and repairing (faulty) equipment.

14. Flight Motivation. This factor includes the intention to become a pilot, to fly and be active in aviation, to overcome difficulties, hardships, and risks involved in flying, and to succeed as an aviator under all circumstances ("keep my license").

Another factor, maturity, seems to have some validity in the psychiatric assessment of the pilot's personality. Since it has not been identified by factor analytical techniques, however, it may be considered as a second or third-order factor highly loaded with related personality variables, such as

experience, judgment, foresight, and self-discipline. Thus, its elements are largely covered by the variables of the other 14 factors.

As to the relationship between the last two factors and aging, only a few data are available. Performance on three mechanical aptitude tests, namely "Dissemble", "Tool Matching", and "Turn", the latter requiring the manipulation of small objects, decreased significantly with age (37). It is not surprising that performance on tasks involving manual and finger dexterity decline with age (as Welford had already shown in 1959) (see 40). The tool matching task required the subjects to identify tools from pictures in a set of five; and this task is more of a perceptual nature than a test of mechanical aptitude. Results of factor analytical studies of the General Aptitude Test Battery indicated that the "Tool Matching" subtest is related to a different set of abilities than either "Disassemble" or "Turn" and does not measure mechanical ability. This is clearly indicated in the studies conducted by Nuttal and Fozard in 1971, and by Fozard, Nuttal, and Waugh in 1972 (see 40).

Finally, it should be mentioned that the motivation to fly also seems to be negatively affected by aging. It has been pointed out by one investigator that the man in a strict flying job has little in the way of advancement and long-range motivation other than his emotional attachment to flying. There comes a time in every aviator's career when a lot of self-discipline and sense of duty must compensate for a decline of the emotional component (76). This seems to be even more the case in non-military and non-commercial pilots. Verra et al. (91) studied the nature and causes of loss of motivation in 600 French light plane pilots (including glider pilots). Based on the responses to a questionnaire concerning the reason for keeping up their flying activities, the authors found a drastic drop in annual flying hours as early as 2 years after obtaining the license and a steady decline and shift of motivating factors after about 8 years. They conclude that this process may be, at least partly, related to the effect of aging (91).

VI. Summary and Conclusions.

The purpose of this report was to survey, summarize, and discuss the information available on the psychological and psychophysiological attributes, processes, functions, and factors which are associated with pilot performance, age, and proficiency. This was done by reviewing the many taxonomies of successful and nonsuccessful pilot behavior, the identification of the human factors involved, and the analysis of the important variables, operational demands, skills, abilities, and personality traits. This included the attempts made by selection and training specialists to establish correlations between psychological testing and training criteria and the operational demands which are often used to measure training success.

Means and methods have been used successfully in the past to define pilot behavior in terms of testable traits. Although the correlations between the psychological test scores and the final criteria - whatever they may have

been - are not impressively high, they seem to serve their intended purpose, namely to predict pilot performance within certain limitations. These limitations are, to a large degree, due to the variability of pilot behavior and traits as well as to operational demands which cannot be fully predicted or controlled at this time. It has been shown, however, that there exists a variety of psychometric, psychological, and operational techniques available which may be employed to overcome this difficulty; those techniques range from such simple tools as paper and pencil tests, through the more complex psychomotor machines to the most sophisticated flight simulators and actual proficiency checks in advanced aircraft. If properly applied, they may be employed for the objective, or at least quantitative assessment of pilot performance.

Newer attempts are being made to assess pilot performance during the training phase and through the total career of the aviator. Through these efforts, tests, and assessment techniques, insight has been gained into the psychological variables and factors which determine career progression and success of the aviator. By using the information collected by many investigators, a total of 14 factors was identified in this study which are assumed to be essential for successful pilot performance. These factors are: 1) perception, 2) attention, 3) reaction, 4) orientation, 5) sensorimotor, 6) stamina, 7) cognition/mentation, 8) experience, 9) interpersonal relations, 10) personality, 11) learning, 12) decision making, 13) mechanical aptitude, and 14) motivation.

In almost all cases, these factors were shown to be age-related, rather independent of each other, and well understood. However, there are a few exceptions where more information is needed in regard to their physiological and psychological components or variables, as well as to their relationship with age and aging. No attempt was made to assign weights to these factors or to rate them with respect to their priority.

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